PREHISTORIC CLOTHING AND ICE AGE CLIMATES

Cold Stress, Neanderthal Extinction

and the Emergence of Modern Human Behaviour

Ian Gilligan

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DECLARATION

I declare that the work in this thesis is the result of my own research and all references to the work of other researchers have been acknowledged. This thesis has not been submitted in whole or in part for any other degree.

Ian Gilligan

Abstract

The interaction between biological and behavioural cold adaptations is explored in relation to Neanderthal extinction and the adaptive success of fully modern humans in the context of rapid climate change during the late Pleistocene. Factors affecting the development of clothing as thermal protection are considered, particularly differing levels of biological cold tolerance (specifically, morphological differences in body shape) leading to differing requirements for clothing between the two species. Morphological adaptation to climate is examined with a study of variation in the femoral neck-shaft angle (NSA) among recent (Holocene) human groups. Results show that this anatomical variable correlates with climate at the population level in the same manner as other indices of body shape, in which case the markedly lower NSA of Neanderthals is consistent with that species possessing greater cold tolerance (and hence reduced clothing requirements) compared to fully modern humans. The archaeological and palaeoenvironmental records are reviewed in terms of evidence for the development of "simple" and "complex" clothing, with intensified cold stress due to rapid and massive climatic oscillations prior to the glacial maximum probably exceeding the capacity of hominins to survive without complex clothing. Greater cold vulnerability among fully modern humans favoured an early adoption of such protection, rendering them pre-adapted to the subsequent thermal challenges, whereas evidence for the use of simple clothing by Neanderthals (based on superior biological cold tolerance) implicates hypothermia as a likely cause of their disappearance in the face of sudden, severe climate changes.

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Definitions

Clothing

The term "clothing" is used here in the strict sense of denoting items that act to enclose or cover the body (Roach-Higgins and Eicher 1995, pp. 9-10). This corresponds to the definition of clothes given in the current (2008) edition of the *Concise Oxford English Dictionary*, "items worn to cover the body"—not necessarily the whole body but any part or portion of the body. Clothing is therefore distinct from decoration or adornment and also from broader terms such as "dress" and "costume", which encompass not only clothes but any form of body modification or alteration (e.g., Eicher *et al.* 2000, p. 4; Entwistle 2000, p. 6; Ember and Ember 2007, p. 281; cf. Barcan 2004, pp. 2-9).

Abbreviations

AMNH	American Museum of Natural History (New York)
AP50	Femoral antero-posterior diameter at 50% MFL (mm.)
AP80	Femoral antero-posterior diameter at 80% MFL (mm.)
BCB	Femoral bicondylar breadth (mm.)
BP	Years before present
CMU	Chiang Mai University Medical School (Thailand)
FHD	Femoral head diameter (mm.)
FLMNH	Florida Museum of Natural History (Gainesville, FL)
IdPH	Institut de Paléontologie Humaine (Paris)
LCHES	Leverhulme Centre for Human Evolutionary Studies (Cambridge)
LE	Loess Event
LGM	Last Glacial Maximum
LSA	African Late (also, Later) Stone Age
MdlH	Museé de l'Homme (Paris)
MFL	Maximum femoral length (mm.)
ML50	Femoral medio-lateral diameter at 50% MFL (mm.)
ML80	Femoral medio-lateral diameter at 80% MFL (mm.)
MSA	African Middle Stone Age
MIS	Marine Isotope Stage
NHM	Natural History Museum (London)

NMNS	National Museum of Nature and Science (Tokyo)
NSA	Femoral neck-shaft angle (°)
PM	Peabody Museum, Harvard University (Boston, MA)
Shape50	Femoral shaft shape at 50% MFL (ML50 ÷ AP50)
Shape80	Femoral shaft shape at 80% MFL (ML80 ÷ AP80)
SAM	South Australian Museum (Adelaide)
SI	Smithsonian Institution (Washington, DC)
SMU	Sapporo Medical University (Japan)

Foreword

Much of the theoretical work (representing a major portion of the thesis) relating to archaeological evidence for the development of clothing in the Pleistocene and its relevance to Neanderthal extinction and behavioural modernity is presented here as two papers, Gilligan (2010) and Gilligan (2007a), which comprise Appendices 1 and 2 respectively on the accompanying CD-ROM. The remainder of the thesis relates to the practical work undertaken, dealing with femoral (primarily NSA) variation in modern humans, which constitutes the main portion (Part 2) of the printed thesis.

To maintain continuity, a number of excerpts from Appendices 1 and 2 are reproduced in the main body of the text, in Part 1 (Chapter 2) summarizing clothing physiology and the distinction between "simple" and "complex" clothing, and in Part 3 (Chapter 13) which includes excerpts relating to archaeological evidence for the use of clothing by Neanderthals and fully modern humans in the Pleistocene.

The printed text is approximately 60,000 words in length and the two papers in Appendices 1 and 2 together total around 20,000 words; the bibliography contains all references cited in the printed and electronic submissions.

PART 1: INTRODUCTION

Chapter 1: Prehistoric Clothing and Human Modernity

This research explores the role of human biological and behavioural adaptations to late Pleistocene thermal environments with regard to the archaeological evidence for two paradoxical patterns in the late palaeolithic record. The first paradox is that, despite the success of Neanderthals and their predecessors in the middle latitudes of western Eurasia throughout a series of ice ages dating from the Middle Pleistocene, when conditions deteriorated during the period leading into the coldest phase of the last ice age around 30,000 years ago, these "cold-adapted" human populations retreated southwards then disappeared. The second paradox relates to fully modern humans, who throughout the last ice age remained well-adapted to the warmer environments of lower latitudes. Yet, during the coldest phase, they not only moved into the middle latitudes previously occupied by Neanderthals but then spread into the more northern and subpolar regions where even Neanderthals had not ventured (and thence, from northeastern Eurasia, over the Bering land bridge into the Americas). The surprising success of modern humans in these circumstances—surprising, that is, given their biological adaptation to tropical conditions—was accompanied by an intensified development of technological and other trends that have figured prominently in the ever-growing (and changing) list of features used to identify "modern human behaviour".

The thesis examines the possibility that these two paradoxes reflect the inter-acting repercussions of biological and behavioural responses to cold exposure. Specifically, it suggests that differing thermal requirements for clothing in the context of changing late Pleistocene climates were crucial factors. The approach is inter-disciplinary, drawing on data from the relevant disciplines:

1. Thermal physiological research, particularly factors affecting human cold tolerance and its limits, and the levels of thermal protection afforded by differing forms of clothing;
2. Palaeoenvironmental reconstructions of thermal conditions during the Pleistocene, especially during the last glacial cycle, with a particular focus on likely minimum winter temperatures and extreme wind chill levels;
3. Physical anthropological evidence for differing biological (morphological) thermal adaptations among Neanderthals and fully modern humans;
4. Archaeological evidence related to the development of human clothing in the late Pleistocene, especially the differing archaeological signatures associated with "simple" and "complex" clothing.

This work builds on the methodology adopted in Gilligan (2007b) to address the clothing "paradox" of Aboriginal Tasmanians, and it takes up some of the wider issues and implications outlined in its conclusions. These include the use of physiological parameters in conjunction with indirect archaeological evidence to render prehistoric clothing less invisible, and the archaeological significance of making a distinction between "simple" and "complex" clothing. The distinction is seen as being relevant to the development of Middle Stone Age (MSA)/middle palaeolithic technologies by both Neanderthal and fully modern human populations during the Middle and Upper Pleistocene, and the development of Late Stone Age (LSA)/upper palaeolithic technologies by some fully modern human populations.

A thermal model for the origin and development of clothing is advocated here, and the reasons why this is important for prehistoric archaeology are outlined (Gilligan 2010). In this approach, principles and findings from thermal physiology are combined with palaeoclimatic data to infer the circumstances in which clothing would be required and hence render prehistoric clothing less invisible. When this method for predicting the presence of clothing is applied to the global archaeological record, it becomes apparent that technological and other correlates of manufacturing appropriate forms of clothing required for human survival correspond broadly to fundamental human behavioural trends and transitions in the late Quaternary. The need for artificial portable insulation that arose within the context of thermal challenges to hominin survival during the Pleistocene connects these archaeological trends tangibly to major palaeoenvironmental fluctuations. For instance, in relation to lithic technologies, the temporal and geographical distributions and relative frequencies of basic tool forms (namely, implements that facilitated the efficient scraping, cutting and piercing of animal hides) may reflect the changing need for adequate protection from cold. Moreover, complex forms of clothing worn on a regular basis began to acquire social functions independent of meeting thermal requirements, and the repercussions of these symbolic and other non-thermal purposes may relate to the emergence of certain archaeological markers of modern human behaviour.

While protection from cold has long been one of the leading theories for the origin of clothing, the thermal model presented here differs in drawing the distinction between "simple" and "complex" clothing based on the physiological properties of clothing, and it suggests that making this distinction renders the prehistoric development of clothing more visible (and relevant) archaeologically. In emphasizing the technological correlates of manufacturing such clothing in the palaeolithic, it claims that major behavioural trends visible in the archaeological record of the late Pleistocene reflect the relevant environmental and biological parameters that either promoted or—in the case of Neanderthals—discouraged the acquisition of adequate (i.e., thermally-effective) clothing.

Two Big Questions

Neanderthal Extinction

Despite intense research and debate, the question of why Neanderthals disappeared remains essentially unresolved (Straus 2005, cf. Klein 2003). Moreover, the debate has raised concerns that dubious preconceptions have biased our interpretations of their capacities compared to those of fully modern humans. As Speth (2004) points out, the posited reasons for their demise are based entirely on absence of evidence and inferred inadequacies on their part. In fact, the available evidence indicates that the adaptive strategies of Neanderthals (and of their immediate forebears) were successful for a long period, encompassing a number of glacial/interglacial cycles (M. White 2006). Neither do existing data provide much support for the notion that Neanderthals were pushed to extinction by competition—direct or indirect—from fully modern humans (cf. Churchill *et al.* 2009), although the fossil record (in contrast to the conclusions drawn from genetic studies) does yield some evidence for inter-breeding (e.g., Trinkaus 2007).

The most extensive recent examination of Neanderthal extinction is the Stage 3 Project (van Andel and Davies 2003). Their findings indicate that sudden, extreme environmental fluctuations late in MIS3 somehow proved too challenging for Neanderthals. Also, the Stage 3 Project found that while Neanderthals were cold-adapted, this was true only up to a point: the archaeological evidence and palaeo-environmental reconstructions indicate that they favoured mild, cool temperature environments and they avoided exposure to more severe cold. However, based on physiological considerations and on their own wind chill estimates, these researchers were reluctant to blame the cold itself for the extinction of Neanderthals.

Modern Human Behaviour

The concept of modern human behaviour has problems of its own (e.g., Klein 2000, pp. 27-33), not least of which is that its more readily identifiable archaeological markers (notably blade-based lithics and bone technologies) have fallen out of favour and are now considered less reliable (e.g., Bar-Yosef 2002). Instead there has been a shift towards more ambiguous markers such as the development of novel cognitive, linguistic or symbolic capacities—for which the archaeological evidence is weak (e.g., Wolpoff *et al.* 2004, pp. 535-538). Furthermore, it has yet to be shown that modern human behaviour bestowed any tangible superiority in terms, for instance, of food procurement strategies—at least not during the critical period between 50,000 and 30,000 years ago—nor why an inferred lack of such capacities should disadvantage Neanderthals at that time (e.g., Adler *et al.* 2006, cf. Klein *et al.* 2004). As the Stage 3 Project shows, the archaeological picture is consistent with Neanderthals retreating southwards into warmer refugia and dwindling in numbers, then disappearing. Fully modern humans equipped with modern human behaviour moved into parts of Europe that had already been essentially vacated by Neanderthals, with stratigraphic gaps (often of a few millennia or more) at sites where the changeover is well-attested. Indeed, Neanderthals lasted in southern Iberia until around 33,000 years ago, long after fully modern humans had moved into northern Spain by around 40,000 years ago (e.g., Hublin *et al.* 1995, Ruiz 2003).

Though discounted by the Stage 3 Project, cold adaptations may have played a direct role, mainly in relation to the development of clothing for thermal reasons (Gilligan 2007a). This argument circumvents many of the difficulties inherent in current approaches, and offers comparatively pragmatic explanations for both Neanderthal extinction and the emergence of certain archaeological markers of behavioural modernity.

Thesis Rationale

The main proposition here is that an interaction between the two basic types of cold adaptation—biological and behavioural—defines the overall adaptive strategy of a population or species, and the consequences of that interaction will determine the ultimate success (or failure) of that adaptive strategy in a given environmental context. A corollary is that adaptive success pertains only in a given environmental context: should environmental (e.g., climatic) conditions change, strategies that were previously successful may prove inadequate. The extent and especially the rate of change is important, as differing strategies will vary in their capacity to respond. Rapid climate change can test the flexibility and the limits of an adaptive strategy, and favour a shift in emphasis (e.g., from biological to behavioural adaptations). Similarly, in these circumstances, the prior development of certain adaptations may prove particularly advantageous in the new conditions, rendering them pre-adaptive, and a population that has acquired pre-adaptations may be in a better position to respond successfully to the change in conditions.

This study examines the interaction between biological and behavioural cold adaptation by focusing on one aspect of biological cold adaptation (morphological variation) and one aspect of human behavioural cold adaptation (clothing). It then explores the potential relevance of the interaction between biological and behavioural cold adaptations for hominins in the rapidly-changing climatic conditions of the late Pleistocene. The morphological aspect relates to thermal role of body build and the behavioural aspect to the minimum thermal requirements for clothing.

Study Design

The study is comprised of two components, one practical and the other theoretical. The practical component involves a study of morphological variation among recent (Holocene) humans in relation to climate and clothing, and the theoretical component to an examination of the palaeolithic and palaeoenvironmental records in relation to Pleistocene climate change and archaeological evidence for the development of clothing. Findings from the morphological study of recent human populations are extrapolated to the late Pleistocene in terms of evidence for differing morphological cold adaptations and use of clothing between Neanderthals and fully modern humans. The aim is to assess the possible role of this interaction in the demise of Neanderthals and the ultimate success of fully modern humans in Eurasia during rapid and extreme climate changes in the late Pleistocene, i.e., between approximately 40,000 and 20,000 years ago.

The theoretical component entails an extensive review of the archaeological literature and the presentation of a modified thermal model for the prehistoric development of clothing. This model draws a distinction between "simple" and "complex" clothing and utilizes existing data from thermal physiology and palaeo-environmental sciences to render palaeolithic clothing more "visible" archaeologically. It proposes that, once rendered "visible" in this manner, the development of clothing for thermal reasons allows some of the major trends in the palaeolithic record of the late Pleistocene to be interpreted as interactions between biological and behavioural adaptations to climate change. Specifically, the differing technological and other behavioural capacities between Neanderthals and fully modern humans are seen as reflecting different requirements for clothing based on their differing biological capacities to adapt to cold stress. It suggests that the severity and rapidity of climate change in the late Pleistocene exceeded the biological capacity of any hominins to survive in Eurasia without adequate behavioural pre-adaptation in the form of complex clothing, and that the archaeological record provides evidence that fully modern humans had begun to develop the requisite technologies earlier in the last glacial cycle due to their greater biological vulnerability to cold stress.

The practical component of the study focuses on the extent to which variation in body shape at the population level may reflect both biological adaptation to thermal environments and also any buffering or insulatory effects of the regular use of thermally-effective clothing. In relation to Neanderthals and fully modern humans during the late Pleistocene, the more stocky, "cold-adapted" shape of the former may indicate not only greater biological cold adaptation but also minimal buffering from cold stress due to clothing, whereas the more linear, "tropical" body shape of the latter would indicate not only greater biological cold vulnerability but also adequate thermal buffering from cold stress due to the acquisition of "complex" clothing.

Body shape is examined here using an extensive study of morphological variation in the femur, insofar as certain anatomical femoral features may vary in relation to body shape. One of the most variable anatomical features of the human femur is the angle formed by the femoral neck in relation to the shaft, and it is this feature which forms the focus of the present study.

Femoral Neck-Shaft Angle (NSA)

Variation in the angle of the femoral neck relative to the shaft (the neck-shaft angle, or NSA) is the subject of ongoing debate as to whether differences between modern (Holocene) human groups as well as among Pleistocene hominins reflect climatic adaptation (in relation to body shape) or habitual activity patterns (as a reflection, for instance, of forager, agricultural, or urban lifestyles). Among late Pleistocene hominins, the lower NSA of Neanderthals, for example, has been interpreted as a corollary of their more stocky, cold-adapted body build (e.g., Weaver 2003) and, alternatively, as an outcome of a more physically demanding and/or less sedentary lifestyle (Trinkaus 1993). Among modern humans, average NSA varies markedly between groups in different regions. Recent studies have explored variation in NSA in relation to climate, but interpretation of results has been limited by measurement issues, small sample sizes, and the limited use of climatic proxies (primarily latitude). Since proximal femora are generally among the most common and well-preserved elements in skeletal and archaeological collections, the NSA may provide a useful index of variation in morphological cold adaptation among hominin groups. Skeletal collections from as many regions world-wide as possible were sought to explore variation is this femoral parameter (along with other measures such as head diameter, maximum femoral length, cross-sectional shaft dimensions and bicondylar breadth). This study reports findings based on extensive sampling of femora among modern (Holocene) human groups, totaling more than 8,000 femora from over 80 countries. Variation in average NSA is examined in relation to meteorological indices (mean annual and seasonal temperatures) as well as latitude as a climate proxy, and also the use of clothing and other lifestyle variables—economic category (forager, agricultural, urban) and mobile *vs.* sedentary lifestyles. In addition, this extensive global sampling (by far the largest database on the human NSA assembled to date) is utilized to address a number of unresolved anatomical questions, namely whether there is evidence for consistent variation in the femoral NSA in relation to gender, age and side (i.e., left-right, or bilateral, asymmetry).

Thesis Structure

The practical component of the thesis—the femoral NSA study—comprises the major proportion of the printed thesis presented here; the theoretical components are largely in two papers, the first dealing mainly with Neanderthal extinction (Gilligan 2007a) and the second dealing with archaeological evidence for the palaeolithic development of clothing and its relevance (Gilligan 2010). To minimize duplication, these are contained on the accompanying CD-ROM, as Appendices 1 and 2 respectively, with only brief summaries and selected excerpts and figures reproduced here to provide continuity. The printed thesis comprised three parts:

Part 1: the remainder (Chapter 2) briefly summarizes necessary background material that is covered in detail in Appendices 1 and 2;

Part 2 (Chapters 3 to 12) presents the NSA study in its entirety;

Part 3 (Chapters 13 and 14) discusses the implications of the NSA study for hominin adaptation in the late Pleistocene, and includes some excerpts from Appendices 1 and 2 relating to archaeological evidence for palaeolithic clothing, the use of simple clothing by Neanderthals and the adoption of complex clothing by fully modern humans.

Chapter 2: Biological and Behavioural Cold Adaptations

The background material summarized in this chapter begins with the thermal physiology of clothing and the distinction between "simple" and "complex" clothing, including the predicted technological correlates. Biological cold adaptation is then discussed in relation to climatic variation in body shape among Neanderthals and fully modern humans, as is the likely buffering effect of clothing. The remaining background material appears in the opening sections of Appendix 2. This includes the main biological reason for human cold vulnerability (a lack of sufficient body hair cover), along with theories as to why we became denuded, together with a summary of the recent genetic evidence from lice studies relating to the origins of both "nakedness" and clothing. The dominant feature of the palaeoenvironmental record of the Pleistocene is reviewed, namely the series of ice ages spanning the latter stages of hominin evolution, which exposed the unusual thermal vulnerability of a denuded primate. Also included in Appendix 2 is a critique of theories of clothing origins. The argument in favour of thermal origins is discussed: in essence, a thermal model is the most parsimonious, and it is consistent with all available lines of evidence.

Clothing Physiology

The thermal insulating properties of clothing are documented in studies of clothing physiology (e.g., Siple 1945, Newburgh 1949, Burton and Edholm 1955, p. 58, Fourt and Hollies 1970, Hensel 1981, Watkins 1984). Briefly, it is not the material of clothing that diminishes heat loss so much as pockets of air trapped next to the skin, which reduce the thermal gradient between the body and the external environment. The natural fur of other mammals works in the same manner, trapping warm air between the fibres. There are two widely-used measures of the thermal effectiveness of clothing:

1. The total *thickness*, which gives an approximate indication of how much air is trapped around the skin surface. With a typical four-layered Arctic garment assemblage, a total clothing thickness of 50mm contains a 22.5mm radius of trapped air (Fourt and Hollies 1970, p. 36). Most of the insulatory effect derives from the air between the layers of material, while air trapped within the fibres of each layer is of secondary importance. The choice of material for each layer is usually affected more by issues of comfort, weight, flexibility and permeability (to perspiration and wind) than by differing thermal qualities of materials.

2. The effective thermal resistance of clothing as measured by the *clo* unit (Gagge *et al.* 1941, p. 429). This was determined experimentally using modern-day woven garments for a seated person (body surface area in m^2) at a temperature of 21°C, relative humidity $< 50\%$, with air movement of 0.1 m/s:

   $$1\ clo = 0.18°C/kcal/m^2/hour$$

   Each layer adds around one clo: modern Arctic clothing (4 layers) provides about 4 clo (Sloan 1979, p. 17). However, the utility of clo units for pre-Holocene clothing is limited, for two reasons. First, the measures are derived from modern-day tailored, woven garments, the thermal qualities of which are quite different from those of prepared animal hides and furs. Second, clo units apply to wind-free conditions, and so may give a misleading impression of the protective value at colder wind chill levels, especially where prehistoric garments may have been draped rather than fitted.

In middle latitudes during much of the late Pleistocene, thermal conditions clearly necessitated clothing—especially in northern continental zones where winter minima were lowest and widespread permafrost indicates mean annual temperatures below -7°C (e.g., Kondratjeva *et al.* 1993, Alexeeva and Erbajeva 2000, Goudie 2001, p. 144). Comparable modern-day environments are designated by physiologists as multiple-layer clothing zones (Siple 1949, Auliciems and de Freitas 1976). For example, four layers are *de rigueur* for outdoor survival in Arctic winters (mean monthly temperatures between -10°C and -20°C), and international standards have been established which document the factors determining these minimum clothing requirements in varying environmental conditions (e.g., Olesen 2005, ISO 2007).

Simple and Complex Clothing

A fundamental distinction is drawn here between "simple" and "complex" clothing (Table 1) which has archaeological implications (Figure 1). The distinction is based on physiological principles, and it arises from two aspects that largely determine the thermal effectiveness of clothing. First, whether a garment is fitted, i.e., shaped to fit closely around the body (including limbs) as opposed to being draped loosely over the body. The second aspect is the number of layers, with multiple layers generally requiring that at least the inner layer(s) are fitted. Draped, single-layered clothing provides limited protection, generally up to around 1-2 clo, although a large thick pelt may provide in excess of 4-5 clo (M. White 2006, p. 599). However, regardless of the insulatory potential in still–air conditions, draped garments are prone to wind penetration whereas fitted, multi-layered assemblages offer superior protection from wind chill.

The archaeological significance of the distinction between simple and complex clothing stems mainly from the technological implications. Where the raw materials are animal hides, simple clothing requires little more than basic skin-preparation techniques, mainly cleaning and scraping, achieved most effectively with scraper tools of various descriptions. Complex garments demand that the skins also be shaped, which means cutting, especially in making the cylinders to cover the limbs, and also that these pieces be joined together, usually by sewing. With multiple layers, the inner garments need finer cutting and sewing to achieve the necessary close fit. Complex clothes, in other words, are likely to be associated with more specialised scraping, cutting and piercing implements. In a Pleistocene context, humans with these technocomplexes were better placed to survive more extreme wind chill conditions, while those without such technologies were restricted in terms of their environmental range.

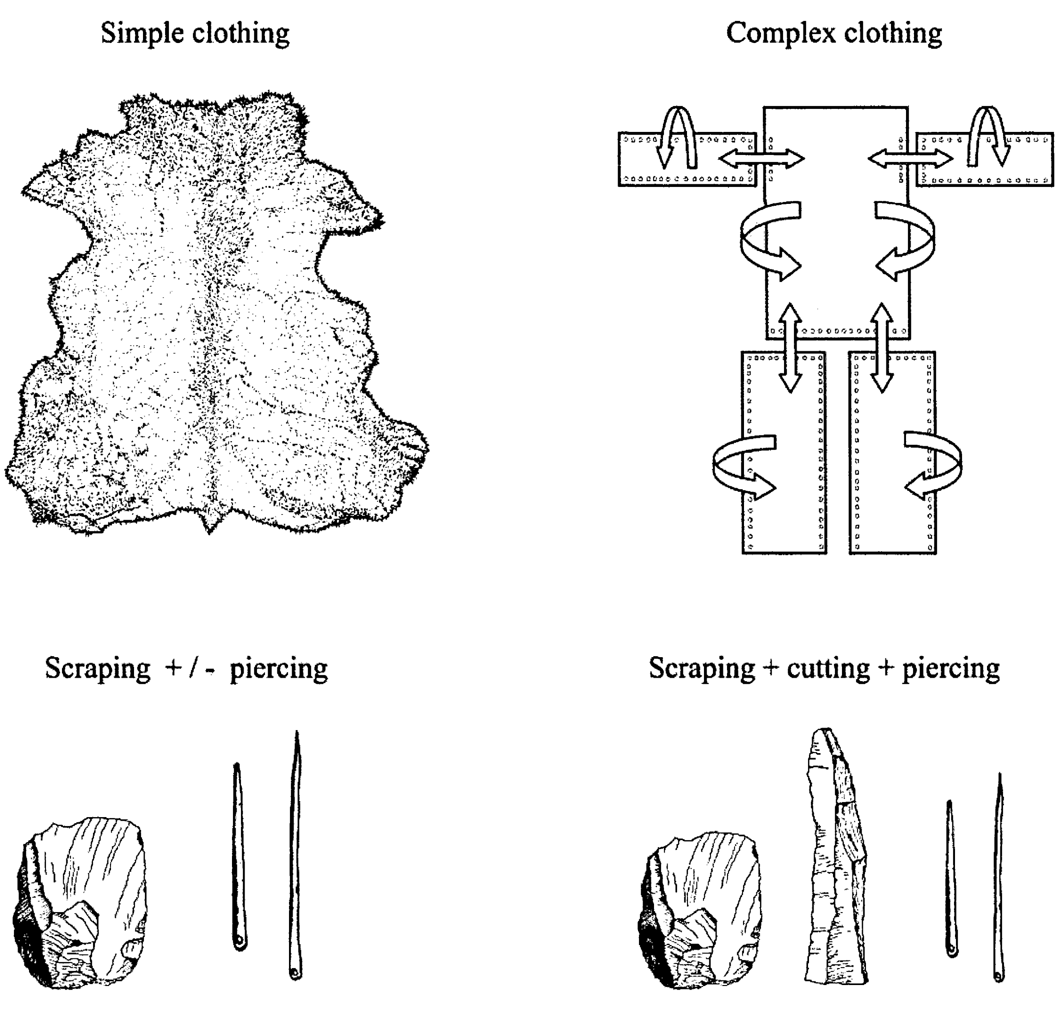
Table 1

Features distinguishing simple and complex clothes.

	Simple clothes	Complex clothes
Structure		
fitted	no	yes
number of layers	1	1+
Thermal physiology		
wind chill protection	poor	excellent
still-air protection (generally)	1-2 clo	2-5 clo
Technology (palaeolithic)		
scraping implements	yes	yes
piercing implements (generally)	no	yes
cutting implements	no	yes
Repercussions		
impairs cold tolerance	no	yes
acquires decorative role	no	yes
acquires social functions	no	yes
promotes modesty/shame	no	yes
becomes habitual	no	yes

Figure 1

Simple and complex clothing and the associated palaeolithic technologies. For simple clothing (left), preparation of the animal pelt generally requires only scraping implements, with the exception of regions (such as in late Pleistocene Tasmania) where only small pelts were available and a number of pelts needed to be joined together to make a single cloak, hence the additional requirement for piercing implements (such as bone awls). Complex clothing (right) requires dedicated scraping, cutting and piercing implements.



Morphological Cold Adaptation

A key aspect of morphological adaptation to the thermal environment involves the relationship between body shape and heat loss, with a more linear body form being more efficient in losing excess heat to the surroundings. Conversely, a more rounded or stocky shape exposes less surface area for a given volume or mass, which is biologically advantageous in circumstances where heat conservation is a priority. At a population level, modern human groups can be differentiated according to overall variation in various measures of body shape. To some extent, these broad differences can be seen as reflecting long-term morphological patterning in relation to geographical distributions (assuming migration histories are taken into account)—and, ultimately, to physiologically-relevant climatic variables, notably temperature indices.

The adaptive relationship between body shape and climate is known in biology as "Bergmann's rule", based on observations of the importance of the surface area to volume ratio in determining an organism's heat balance (Bergmann 1847, p. 601). Similarly, Allen's rule refers to the size of body appendages, with exposed limbs becoming shorter in cooler climates (Allen 1877). Like all rules, that of Bergmann has exceptions, as emphasized by critics (e.g., Geist 1987). With increasing latitude, for instance, body mass first increases but then decreases in some species. This reflects the fact that greater body mass attracts a higher caloric cost, so its net adaptive benefits reach limits, at which point alternative strategies such as increased fur cover can be favored. Phenotype is "the result of a compromise between many conflicting selection pressures" (Mayr 1956, p. 106), and exceptions serve only to illustrate the complexities involved (e.g., Schreider 1975, Katzmarzyk and Leonard 1998). With this caveat, Bergmann's rule has been shown to apply among numerous bird and mammal species (e.g., Ashton *et al.* 2000, Meiri and Dayan 2003), while among both modern humans and fossil hominins, studies have demonstrated that body mass and shape, head shape, and relative limb proportions correlate with thermal conditions (e.g., Roberts 1978, Trinkaus 1981, Ruff 2002).

The historical background and physiological principles are summarised in Gould (1966) and Ruff (1994). Briefly, body form affects thermal requirements by virtue of the ratio between skin surface area and body volume, or mass. The latter is related to total heat production (through metabolism), while exposed skin surface area plays a dominant role in dissipating body heat. Even minor variations in body shape or size are significant because, as Bergmann observed, surface area and volume vary in unequal proportions to each other: volume varies as the cube, whereas surface area varies as the square, of any linear change in size. These principles predict a lighter, more linear body build in warmer environments, and a heavier and more stocky build in cooler regions.

Late Pleistocene Hominins

Among fossil hominids, indices of body shape and limb proportions have been shown to correlate with thermal conditions (e.g., Ruff 1991, 1994, Holliday and Falsetti 1995). For example, the brachial and crural indices of "cold adapted" Neanderthals are in the lower range compared with both early and contemporary

Homo sapiens, and the indices are lower among European than Near Eastern Neanderthals (Trinkaus 1981, pp. 189-209). A similar trend is evident in the claviculo-humeral index (ibid.). For the latter, a high index is an indicator of a more stocky body build. It is greater in Neanderthals compared with modern humans in late Pleistocene Europe, and also in Europeans compared with Near Eastern Neanderthals. Among earlier hominins, the tall, linear build of *H. ergaster* was well-adapted to open, semi-arid environments whereas the shorter stature and the limb proportions of the Australopithecines were adapted to more closed, wet tropical environments (Ruff 1993, pp. 56-58). With regards to head size and shape, a trend to larger and rounder heads is a general feature of hominid evolution associated with brain expansion and the adoption of an erect posture (Weidenreich 1945), with a further likely effect of cold adaptation among more recent hominids throughout the Pleistocene (Beals *et al.* 1983).

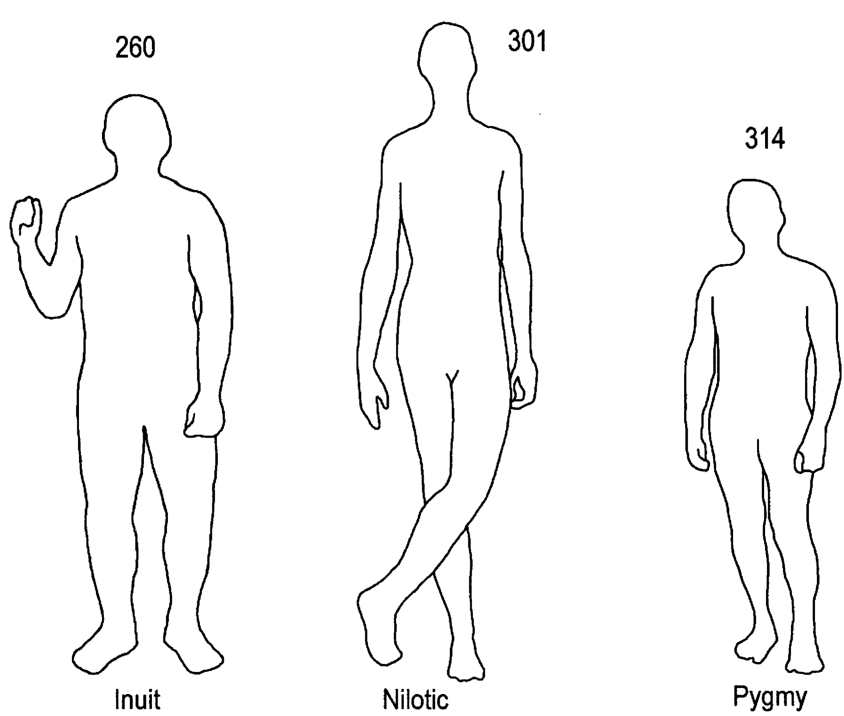
Fully modern humans who replaced Neanderthals in late Pleistocene Europe retained tropical limb proportions—e.g., a high crural index (tibial length x 100 ÷ femoral length)—but nonetheless showed a small and gradual reduction in total lower limb length, which may reflect "climatic selection due to the glacial cold" (Holliday 1999, p. 561). Indeed, the Neanderthal-like limb proportions of the juvenile skeleton dated to around 25,000 years ago in Portugal (Lagar Velho 1, known as the "Lapedo child") were among the unusual features that first alerted its discoverers to its possible status as "hybrid" between cold-adapted Neanderthals and morphologically tropical modern humans (Ruff *et al.* 2002, p. 390, Zilhão and Trinkaus 2002, p. 21), for which further anatomical evidence has since emerged (e.g., Bayle *et al.* 2010).

Modern Humans

Studies in physical anthropology have demonstrated consistent associations between environmental parameters and a number of major trends in modern human morphology. Body mass (or weight), body shape, head shape, and relative limb proportions for instance correlate with thermal conditions (Figure 2), particularly mean annual temperature. These trends exist on a global and on a continental or regional scale (e.g., Hiernaux 1963, Roberts 1978, Crognier 1981, Beals *et al.* 1983, Gilligan and Bulbeck 2007). Limb proportions have also been shown to vary with altitude, for instance between coastal and highland groups in Peru (Weinstein 2005).

Figure 2

Differing body shapes and limb proportions among modern human groups, with the ratios of surface area to body mass (cm^2/kg) (redrawn from Ruff 1993, p. 54)



Besides temperature, another key environmental variable identified in studies of physical variation among human populations is moisture (humidity and, to a lesser extent, rainfall). Environmental moisture has significant thermal aspects, both in reducing the effectiveness of hair cover as insulation and in affecting the rate of heat loss from the skin surface. High humidity, for example, impedes evaporative cooling from perspiration in hot climates, adding to heat stress, while high rainfall results in additional evaporative heat losses from a wet skin surface, particularly where wind speeds are high, adding to cold stress. The wind chill effect in itself has been implicated as a factor in the stocky body shape of Polynesians. Their relatively large body mass, thick limbs, round heads and reduced surface area to volume ratio appear better adapted to higher latitudes, rather than to a tropical Pacific habitat. However, despite mild mean temperatures, their oceanic environment entails exposure to wind chill exacerbated by evaporative cooling due to high moisture levels, resulting in greater rates of heat loss and the risk of hypothermia (Houghton 1990).

Moisture in the form of humidity and rainfall can directly affect the relationship between temperature and body shape. The cooling advantage of a higher surface/volume ratio in hot environments depends largely on evaporation of perspiration from the skin surface. Evaporative cooling is compromised in conditions of high atmospheric moisture content, especially if coupled with reduced wind chill—as it is in relatively closed (e.g., heavily forested) environments. This has been posited as an explanation for the reduced body size of the Pygmy and Negrito populations residing in hot, humid rainforest habitats. In these circumstances, where keeping cool is the main priority, a large exposed skin surface is of little use for evaporative cooling but a lower body mass means less metabolic heat production, so the net thermal result is reduced body size (Hiernaux *et al.* 1975, pp. 7-9, Cavalli-Sforza 1986, pp. 394-402). In Australia, the small stature of Aboriginal groups in the hot rainforest areas of north Queensland (Tindale and Birdsell 1941) may be more a consequence of these local environmental conditions, than any genetic contribution from ancient "Negrito" immigrants into the area as hypothesised by Birdsell (1967).

Australian Aborigines

In comparative studies of modern human groups, the Australian Aborigines emerge with a distinctly tropical pattern, i.e. a linear body build with relatively long, slender limbs (Roberts 1978, p. 22). Nonetheless there are reasons for anticipating thermal trends in Aboriginal morphology that should include a less linear build, less dolichocephalic head shape, and reduced limb proportions in the cooler southern latitudes. One reason is the long time depth of their occupation of the continent—at least 45,000 years for the mainland (Thorne *et al.* 1999, O'Connell and Allen 2004) and 35,000 years for Tasmania (Jones 1995, Cosgrove 1999). Another reason is exposure to colder conditions during the late Pleistocene, especially in the southern regions and in Tasmania.

In the Australian context, Gilligan and Bulbeck's (2007) re-analysis of the Birdsell (1993) database showed a more linear build correlating with higher mean temperatures and a broader or stockier build with lower temperatures (especially colder winters). The limb length measures showed consistent environmental correlations—positive for temperature and negative for wind velocity. Wind chill correlated positively, meaning that limb lengths were reduced with lower (colder) wind chill figures, and the limb correlations in general were stronger for the lower compared to the upper limbs, and for distal compared to proximal limb segments, consistent with Allen's rule. With regard to cranial size and shape, the cranial module, a measure of overall cranial size, increased as winter temperatures declined, and the cephalic index, a measure of cranial shape (cranial breadth ÷ length), correlated negatively with mean and summer temperatures, indicating a less elongated (or dolichocephalic) head shape in cooler conditions. Both the cranial module and cephalic index correlated negatively with wind chill temperature. In other words, as temperatures fall and the wind chill effect increases, heads tend to become larger and rounder, as expected from Bergmann's rule.

Given the duration (35,000 years) of the human presence in Tasmania—which includes exposure to climatic conditions colder than the present during the LGM—and given also the likely genetic isolation of the population during the last 10,000 years, this southernmost corner of Sahul provides an excellent example of how modern humans can adapt physically to their local environmental conditions over a prolonged timespan. Most of their distinctive physical characteristics may reflect a long-term adjustment of tropical Aboriginal features to a generally cool and moist mid-latitude environment (Gilligan 2007b, pp. 95-96). While quantified data are sparse and most of the available evidence derives from ethnohistorical descriptions, the physical characteristics that typify Tasmanians appear consistent with expect-ations based on Bergmann's and Allen's rules. In comparison to mainland Australian averages, their head shape is broader and rounder, shoulders broader, and extremities smaller. A retention into the Holocene of these morphological cold adaptations acquired during the late Pleistocene would reduce physiological requirements for clothing, which may explain an otherwise puzzling paucity of clothing used by Tasmanians at the time of European contact (ibid., pp. 86-88).

Body Shape and Clothing

The role of environmental adaptation as an influence on human morphology has long been a central interest in physical anthropology, and the possible effects of climatic variables such as changing temperature regimes (past and present) remain a major focus of research. Adaptation can be behavioural as well as biological, and both these basic evolutionary strategies can interact. Since at least the Middle Pleistocene and particularly the late Pleistocene, humans have developed increasingly elaborate (and thermally effective) forms of artificial insulation from the environment, concomitant with a generally increasing pace of social and technological change, notably in recent millennia. One likely consequence is a reduction in selection pressure for biological adaptation to external environmental conditions. This process has allowed the expansion of hominins from their tropical and subtropical homelands into temperate and subpolar regions, with some populations eventually penetrating and occupying high latitudes even during colder phases within the last couple of glacial cycles. In the modern world, the success of behavioural measures resulting in greater protection from (and modification of) local thermal conditions should become visible as a trend towards a decoupling of morphological and climatic variation, and this should be most discernible among those human groups utilizing the more sophisticated forms of behavioural adaptation.

Of the three fundamental behavioural adaptations to cold that humans developed in prehistoric times—the use of fire, shelter and clothing—it is the last innovation that is probably the most recent and, in terms of its repercussions, the most important from a thermal perspective. Among the reasons is that, firstly, clothing provides the most consistent physiological protection and, secondly, it is highly portable. This means that the adoption of clothing may be associated with a more prominent mismatch between morphological and environmental variation among those modern human groups where its use has been most prolonged and habitual—especially where its regular use has become increasingly mediated by cultural factors that can operate more-or-less independently of thermal requirements.

During the late Pleistocene, there is a marked discontinuity between Neanderthal and early modern humans in Europe in terms of limb and trunk proportions, with fully modern humans subsequently showing a temporal trend over some 20,000 years from tropical to more temperate body proportions (Holliday 1997). The retention of tropical limb proportions among fully modern humans in Europe during the LGM might be attributable to "improved cultural buffering"—which, for reasons of thermal physiology, would include tailored, multi-layered garment assemblages—although extraneous gene flow from Africa could also be responsible, with a subsequent shift to more cold-adapted body proportions attributable to the "harsh climate" of the LGM (ibid., pp. 442-444).

PART 2: A GLOBAL STUDY OF THE FEMORAL NSA

Chapter 3: Femoral NSA and Climate

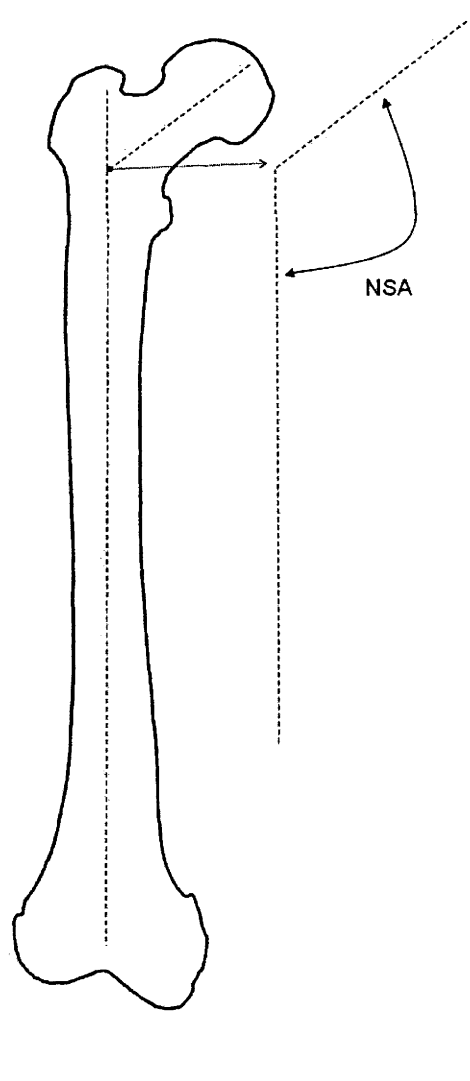
Numerous studies in physical anthropology have explored the possible adaptive relationships between morphology and climate by comparing body shape measures in different human groups and relating these to climatic indices or proxies such as latitude and average annual temperatures. The degree to which certain measures of body shape might be useful for this purpose is a matter of some debate, as climatic adaptation is only one of a number of factors which are known to exert an influence on body form. The others include, for instance, patterns of nutrition, diet, disease, lifestyle and levels (and types) of physical activity, particularly during early development and childhood.

With respect to skeletal measures of body shape, one poorly-researched measure that has recently attracted considerable attention in the literature concerns the shape of the femur and, specifically, the angle formed between the neck and the shaft at its proximal end (Figure 3)—designated variously over the years as the collodiaphyseal angle, cervicodiaphyseal angle, or the angle of inclination, and nowadays known widely as the neck-shaft angle (NSA).

This study attempts to address outstanding questions regarding the nature and extent of variation in the NSA between and within modern human groups and, insofar as such variation can be demonstrated reliably with available data, examine whether the evidence might support the utility of the NSA as an osteological indicator of morphological adaptation to thermal conditions. Further questions relating to the possible confounding effect of behavioural adaptations (namely, the use of clothing) on any relationship between morphological and environmental variation will then be discussed.

Figure 3

The femoral neck-shaft angle (NSA) shown on the right femur (anterior view).



The Femoral Neck-Shaft Angle (NSA)

The extent to which the NSA in humans varies in relation to climate (or whether, instead, its variation relates more to factors such as lifestyle and activity levels) remains an open question despite considerable research in recent years. Trinkaus (1993, 1994) compared the NSA of Neanderthals to near-modern (Qafzeh-Skhul) and fully modern (upper palaeolithic) Eurasian hominins (Table 2). He interpreted the higher NSA of near-modern humans (Qafzeh-Skhul) in the Near East as reflecting of a less mobile and less physically-demanding lifestyle compared to Neanderthals (cf. Arensburg 1994), despite the more stocky build of Neanderthals being consistent with their having developed morphological adaptations to cooler European environments (and hence possessing a lower NSA). In supporting his conclusion, Trinkaus cited NSA data on 21 modern samples from various sources grouped into three lifestyle categories (foraging, agricultural and urban). The NSA showed a modest increase across these groups, which he interpreted as reflecting the shift to a more sedentary lifestyle rather than any differences in thermal conditions. A subsequent study employing samples from 30 modern groups reported a similar trend, and specifically discounted a climatic association after finding no significant trend between four groupings (Sub-Saharan African, European/Mediterranean, east Asian and Native American) and climate as measured by latitude (Anderson and Trinkaus 1998, p. 284).

Table 2

List of femoral NSA measures of fossil hominins (data from Trinkaus 1993, p. 406, Arensburg 1994, p. 450, Trinkaus and Jelínek 1997, p. 65)

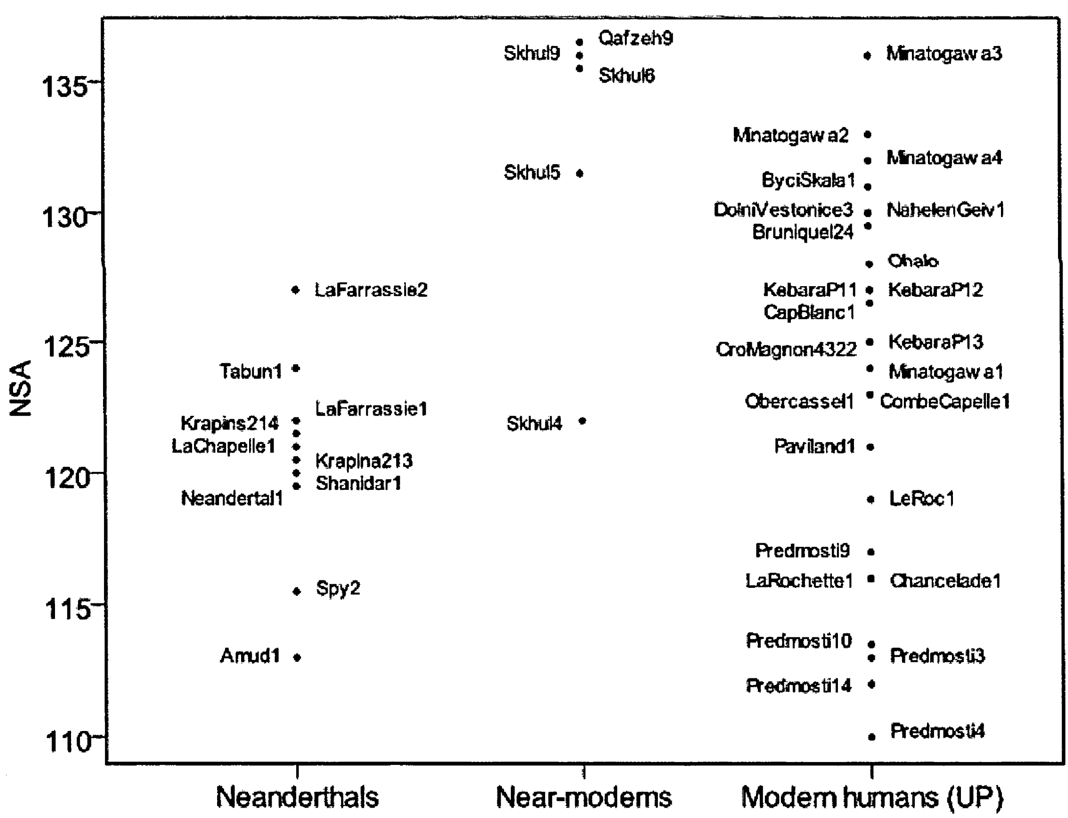
Species	*Specimen*	*NSA*
Neanderthals	Amud 1	113°
	Krapina 213	120.5°
	Krapina 214	121.5°
	La Chapelle 1	121°
	La Ferrassie 1	122°
	La Ferrassie 2	127°
	Neandertal 1	119.5°
	Shanidar 1	120°
	Spy 2	115.5°
	Tabun 1	124°
Neanderthal mean	$n = 10$	120.4°
Near-modern humans	Qafzeh 9	136.5°
	Skhul 4	122°
	Skhul 5	131.5°
	Skhul 6	135.5°
	Skhul 9	136°

Near-modern mean	$n = 5$	132.3°
Fully modern humans	Bruniquel 24	129.5°
	Býčí-Skála 1	131°
	Cap Blanc 1	126.5°
	Chancelade 1	116°
	Combe-Capelle 1	123°
	Cro-Magnon 4322	125°
	Dolní Vestonice 3	130°
	Kebara P11	127°
	Kebara P12	127°
	Kebara P13	125°
	La Rochette 1	116°
	Le Roc 1	119°
	Minatogawa 1	124°
	Minatogawa 2	133°
	Minatogawa 3	136°
	Minatogawa 4	132°
	Nahel en-Gev 1	130°
	Obercassel 1	123°
	Ohalo	128°
	Paviland 1	121°
	Předmostí 3	113°
	Předmostí 4	110°
	Předmostí 9	117°

	Předmostí 10	113.5°
	Předmostí 14	112°
Fully modern human mean	$n = 25$	123.5°

Figure 4

Scatterplot of femoral NSA measures of fossil hominins (data from Table 2)

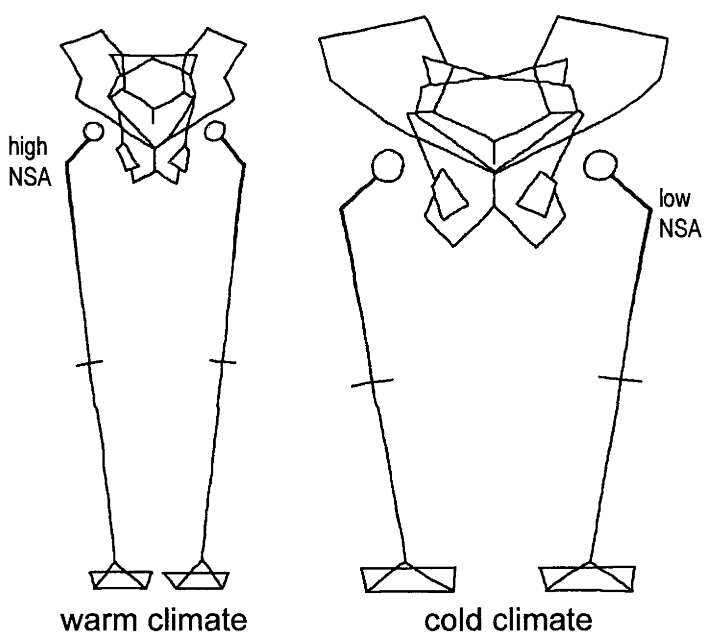


Comparing the NSA for Neanderthals, near-modern and fully modern humans in Table 2 (shown in Figure 4), the Neanderthals mean (n = 10) of 120.4° is markedly lower than that of the near-modern (n = 5) sample, 132.5°, but only moderately (3.1°) lower than the mean NSA (n = 25) for the fully modern sample, 123.5°. However, the sample sizes are small, and the fully modern sample includes a group of five femora from the Gravettian site of Předmostí in the Czech Republic which, as a discrete fully modern sample, comprises unusually low NSA measures (113°, 110°, 117°, 113.5°, and 112°). These were published in 1938 and, as the specimens were destroyed during the Second World War, it is not possible to check the accuracy of the measurements. Without the Předmostí sample, the average NSA for the fully modern sample (n = 19) increases to 126.1°—comparable to that of recent (Holocene) modern humans—resulting in a difference of 5.7° in mean NSA between the Neanderthal and modern human samples from the Pleistocene.

In contrast to Trinkaus' interpretation, Weaver (2003) analyzed 39 anatomical markers on the hip and femur among human groups from warm and cold climates and found that the lower NSA's of Neanderthal femora are consistent with a cold-climate morphology (Figure 5). Interestingly, he suggested that the lower NSA among cold-climate groups may reflect differing developmental forces on the femoral neck secondary to climate-related differences in body proportions, rather than any purported differences due to lifestyle or activity levels (ibid., p. 6928). In other words, a broader, more cold-adapted body shape will increase biomechanical loading on the femoral neck during early development, resulting in a lower NSA. He concluded that "most if not all clear contrasts in shape between the femora of Neandertals and near-modern humans seem to be secondary consequences of differences in climate-induced body proportions", although "the exact mechanical link between neck-shaft angle and body proportions needs to be established" (ibid.).

Figure 5

Differing NSA associated with warm-climate (left) and cold-climate (right) pelvic shape and lower limb proportions (redrawn from Weaver 2003, p. 6928)



Among recent modern humans, the NSA varies quite widely even within small population samples, with adult values generally in a range between 120° and 140°; values of <120° and >140° (known as coxa varus and coxa valgus respectively) are rare but do occur. Not only is the variation marked within groups, NSA can show considerable asymmetry between left and right, although there would appear to be no consistent side difference. Whether a gender difference exists is uncertain: anatomy textbooks often state that the NSA is somewhat lower on average in females (given the broader pelvic shape), but available evidence in physical anthropology suggests that "any sexual differences are small and inconsistent" (Anderson and Trinkaus 1998, p. 283). The NSA is higher in juveniles and declines during childhood, usually reaching adult values by early adolescence after which it remains stable—though there may be a minor further decline with advanced age (e.g., 80 years and over).

Additionally, the femoral NSA is of considerable medical interest, as it has been implicated in the varying susceptibility of different groups to hip osteoarthritis and risk of hip fracture—a major cause of disability in the elderly and, given the aging population structure in industrialized Western societies and expense of hip replacement surgery, a significant health cost. An early study (Walensky and O'Brien 1968) reported that the lower NSA among American white females compared to American blacks may be a contributing factor to the higher incidence of hip fractures among whites. However, other research findings are more equivocal with respect to the NSA and suggest that reduced bone mineral density (osteoporosis) is the most significant factor—hence a heightened susceptibility to fracture among post-menopausal women (e.g., Cheng *et al.* 1997, Pulkkinen *et al.* 2006, Gnudi *et al.* 2007, Doherty *et al.* 2008).

Measurement Issues

A paucity of research on the NSA is in part attributable to the uncertainties regarding methods for determining the NSA. Two anatomical aspects of the proximal femur can make measurement difficult. The first relates to the highly variable and often irregular contours of the neck itself, which can render definition of the neck axis ambiguous. Even defining the shaft axis is not always straightforward, as there is not uncommonly a degree of curvature in the shaft, most typically anterior bowing. The second relates to the varying amount of anterior rotation of the neck in relation to the shaft—known as anteversion of the femoral neck. This second aspect means that measuring the NSA on a standard osteometric board is not viable, and it is especially problematical where NSA measurements are taken from radiographs, since anteversion (not readily measurable on an osteometric board and not detectable on a standard X-ray) exaggerates the NSA. While various methods and formulæ have been proposed to mitigate or compensate for the consequent error (e.g., Ogata *et al.* 1979, Trinkaus 1993, p. 398), in practice it is preferable to measure the NSA by hand and avoid using NSA data obtained from radiographs (Olsen *et al.* 2009). Alas, much of the older published data on NSA (which is still often cited in the literature) derives from radiographs, and even recent studies utilize radiographs (e.g., Igbigbi 2003). Moreover, notwithstanding the problems of measurement by hand (related essentially to anatomical variability and a lack of reliable anatomical markers), inter- and intra-observer errors have been shown to be acceptably small (usually no greater than 1-2°) in relation to differences in group means (Anderson and Trinkaus 1998, p. 280). As discussed in the next chapter, in this study it was planned initially to measure the NSA using an osteometric board equipped with apparatus designed specifically for measuring angles. However, anteversion of the femoral neck proved an insurmountable problem, and a hand-held goniometer was substituted, with measurements taken by hand on the anterior surface of the femur in a coronal plane parallel to the neck and proximal shaft, which removes any confounding effect of anteversion on the measurement (Trinkaus pers. comm.).

Other Femoral Morphology Issues

Also of interest here are studies looking at osteological indicators of general femoral "robusticity" (i.e., massiveness or stockiness) in relation to climate and activity levels, with an emphasis on cross-sectional shape of the femoral shaft. Pearson (2000) found that while activity levels (hunter-gatherer vs. sedentary lifestyles) probably have an influence, the evidence from a range of modern and fossil groups tends to favor a stronger relationship between robusticity and climate. Wescott and Cunningham (2006) report an activity effect on femoral robusticity in females though not males, associated with horticultural intensification among the Arikara (an American tribe on the Great Plains). Other studies (e.g., Weaver and Steudel-Numbers 2005, Sládek *et al.* 2006, Westcott 2006) either infer a climatic link, or fail to clearly substantiate a mobility/activity effect.

Among Australian Aborigines, Collier (1989) found that midshaft diameters (antero-posterior and medio-lateral) for his Murray Valley sample (n = 120) were relatively low and "gracile", consistent with them occupying the warmest environment of the populations sampled (Inuit, American whites, Arikara Indians, and Romano-Britons from the Poundbury site in England). At the opposite climatic extreme, a study of the indigenous inhabitants of Tierra del Fuego (n = 24) revealed comparatively "robust" femoral shaft indices, consistent with a cold adapted physique, but little evidence for any effect due to differing habitual activity patterns between marine foragers (the Yahgan) and terrestrial hunter-gatherers, the Selk'nam Onas (Pearson and Millones 2003, 2005). The complexity of possible relationships between femoral shape and both climate and activity is underscored by a study comparing the likely contributory roles of habitual activity patterns and climate on upper and lower limb robusticity among four groups—Fuegians, Native Americans, southern Africans and Andaman Islanders (Stock 2006). Results point to a mobility effect proximally and a climate effect distally in the upper limb, and vice versa in the lower limb (i.e., a more prominent climate effect in the proximal femur), and it is suggested that these complex effects "may be confounded by systems of cultural buffering from environmental stress" (ibid., p. 7)—which presumably includes clothing.

Among fossil hominins, Trinkaus and Ruff (1999) found that differences in femoral shaft geometry between Neanderthals and near-modern humans in the Near East (notably, greater medio-lateral diameters among Neanderthals) are probably related to body shape differences rather than any differences in habitual activity patterns. Conversely, Holt (2003) interpreted a shift from a more antero-posteriorly elongated to a more circular cross-section of the femoral shaft between early and late upper palaeolithic and mesolithic modern humans in Europe as reflecting a trend towards reduced mobility, with reduced cortical thickness suggesting reduced bio-mechanical loading. CT scanning of the archaic *Homo* tibia from Boxgrove in England, dated to the MIS 13 interglacial around 500,000 years ago, shows medio-lateral reinforcement comparable to that of Neanderthals and suggests a cold-adapted body shape despite the MIS 13 context (Trinkaus *et al.* 1999a). Yet the associated faunal data indicate a cooler, more temperate climate late in MIS 13, which may signify exposure to winter cold stress and stronger selection for biological thermal adaptations, given the likely absence of effective behavioural adaptations in the form of shelter and clothing (ibid., p. 22).

The late Neanderthal specimen associated with a Châtelperronian culture at Saint-Césaire has a femoral shaft geometry—with medio-lateral reinforcement—consistent with a cold-adapted body shape, and overall cortical thickness suggesting a high body mass even by Neanderthals standards (Trinkaus *et al.* 1999b), which could reflect biological response to greater cold stress in late MIS 3. Similarly, CT scans of the femur of the Tyrolean "Iceman", found at an altitude of 3200m and dating to around 5,000 years ago, show medio-lateral strengthening suggesting a relatively stocky, cold-adapted body build (Ruff *et al.* 2006), which may indicate considerable cold exposure despite the presence of clothing (Spindler 1994, pp. 132-147).

Chapter 4: Pilot Study

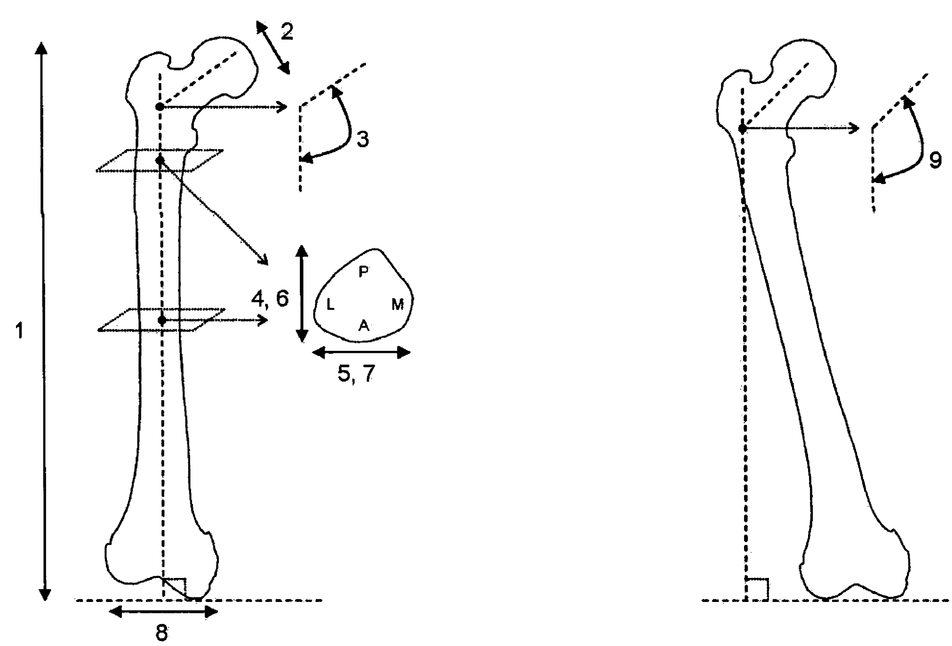
Prior to examining modern human skeletal collections in various institutions, a pilot study was undertaken to assess the measurement issues and also the practicalities of the research (e.g., the extent of completeness of femora and range of anatomical variation in a typical collection, and the likely time required to measure a sample of given size). This was carried out in March-April 2007 during a three-week period at the Congdon Anatomical Museum, Siriraj Hospital in Bangkok, Thailand. This museum houses a well-provenanced collection of very recent local material (dating from *c.* 1949), with most individual specimens identified with information on gender and age at death. Initially, it was planned to measure nine anatomical variables on the femora using an osteometric board and digital calipers (Figure 6):

1. Maximum femoral length (MFL, mm.)
2. Femoral head diameter (FHD, mm.)
3. Femoral neck-shaft angle (NSA, °)
4. Subtrochanteric antero-posterior shaft diameter, measured at 80% of MFL (AP80, mm.)
5. Subtrochanteric medio-lateral shaft diameter, measured at 80% of MFL (ML80, mm.)
6. Mid-shaft antero-posterior shaft diameter, measured at 50% of MFL (AP50, mm.)

7. Mid-shaft medio-lateral shaft diameter, measured at 50% of MFL (ML50, mm.)
8. Bicondylar breadth (BCB, mm.)
9. "Anatomical" neck-shaft angle (ANA, °), measured with the femur placed in the "anatomical" position, i.e., with the inferior border lying horizontally.

Figure 6

The nine femoral variables as originally planned



1 femoral length (maximum) [MFL]
2 femoral head diameter [FHD]
3 neck-shaft angle [NSA]
4 A-P diameter (80% – subtrochanteric) [AP80]
5 M-L diameter (80% length) [ML80]
6 A-P diameter (50% length – mid-shaft) [AP50]
7 M-L diameter (50% length) [ML50]
8 bicondylar breadth [BCB]
9 "anatomical" neck angle [ANA]

The total Bangkok sample in this pilot study is 243 femora representing 131 individuals, comprising 112 yielding both left and right femora (n = 224) , and the remaining 19 with single femora. Age, gender and side data are shown in Table 3.

Table 3

Demographic and side data for the Bangkok sample

Age	data available	137 / 243	56%
	mean	48.5 years	
	minimum	20 years	
	maximum	87 years	
	SD	18.2	
Gender	data available	137 / 243	56%
	male	95	70%
	female	42	30%
Side	left	124	51%
	right	119	49%

The age range in this Bangkok sample is excellent, spanning young adults (juveniles and adolescent specimens being excluded due to the NSA reaching its stable adult level during adolescence) to the elderly, with the latter offering the prospect of exploring whether the NSA may decline slightly with advanced age. There is a male bias in the sample, but the side (left/right) distribution is even.

Measurement Techniques

Initially, MFL, NSA and ANA were measured on an osteometric board equipped with apparatus designed specifically for measuring angles (Figure 7), while FHD, AP80, ML80, AP50, ML50 and BCB were measured using digital calipers (Figures 8-9).

Figure 7

Osteometric board with angle-measuring apparatus

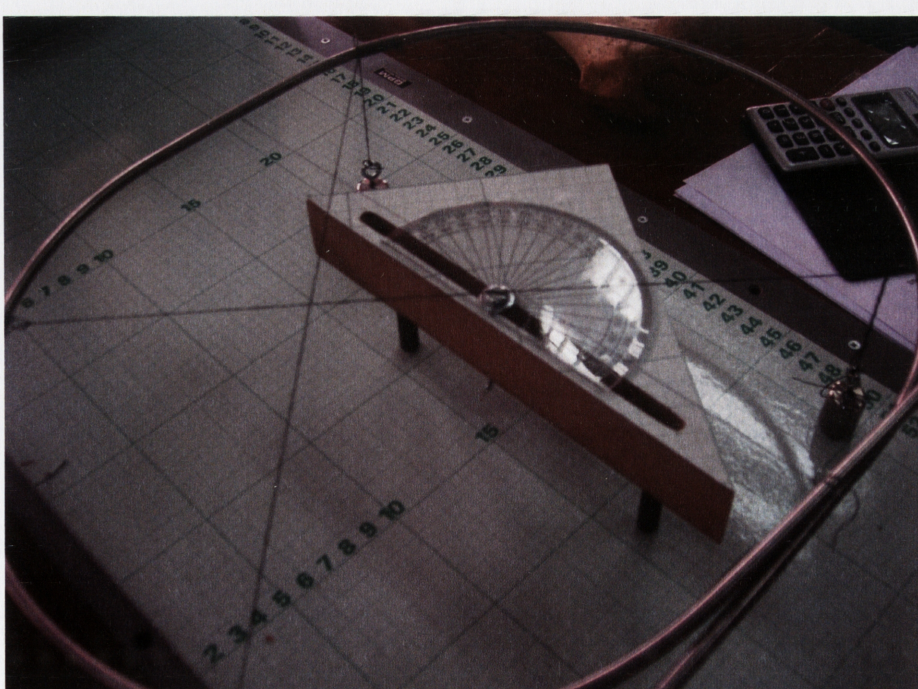


Figure 8

Measurement of femoral ANA on the osteometric board

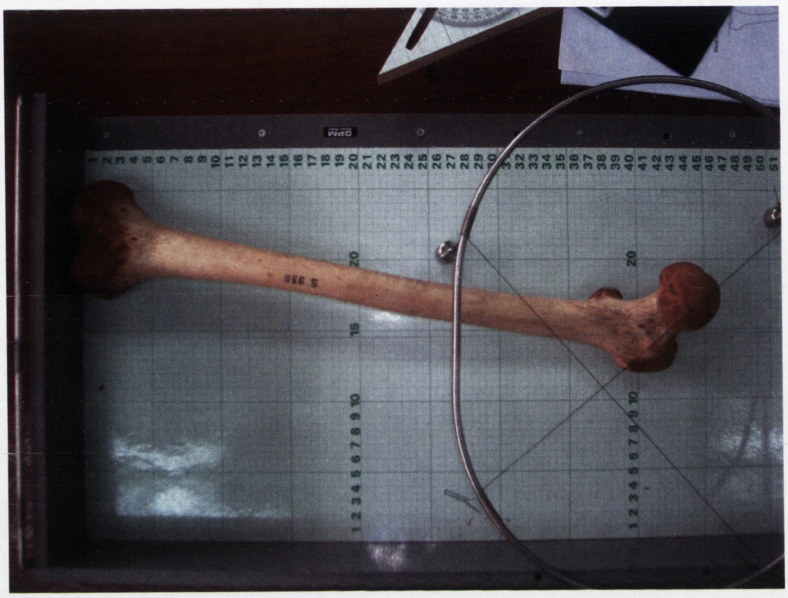


Figure 9

Measurement of FHD using digital calipers

It became evident that using the osteometric board to measure NSA and ANA led to exaggeration of the angles, due to anteversion (anterior rotation) of the femoral neck in virtually every case (Figure 10). Subsequent comparison of the NSA measured with the osteometric board and with a hand-held goniometer (placed in a vertical plane parallel to the neck axis) revealed an unacceptable mean error of ~5°. Thereafter, the NSA was measured solely with the goniometer (Figure 11) and specimens previously measured on the osteometric board were re-measured with the goniometer. However, the ANA (which had been intended as more physiologically-relevant femoral neck-shaft angle) could not be measured reliably in this fashion and, as a consequence, the ANA variable was abandoned.

Figure 10

Anteversion of the femoral neck

Figure 11

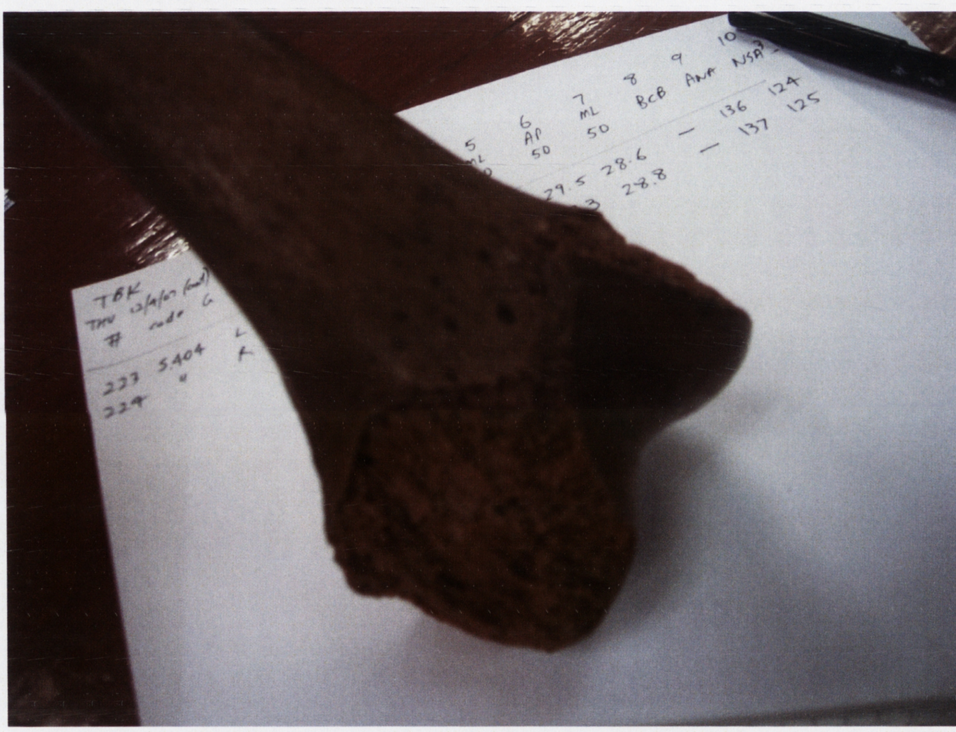
Measurement of the NSA with a hand-held goniometer

Specimen Completeness and Variation

Being a very recent (and not an archaeological) sample, the vast majority of femora were complete, with omission of measurements due to damage being relatively uncommon. While proximal damage preventing measurement of NSA was rare, damage to the femoral head occasionally prevented measurement of FHD. A more common problem was damage to the distal epiphysis; if extensive (e.g., Figure 12), this meant that BCB and MFL (and hence also AP80, ML80, AP50 and ML50, which require MFL for their determination) could not be measured. In the pilot study, femora with substantial distal epiphyseal damage preventing measurement of MFL were excluded.

Figure 12

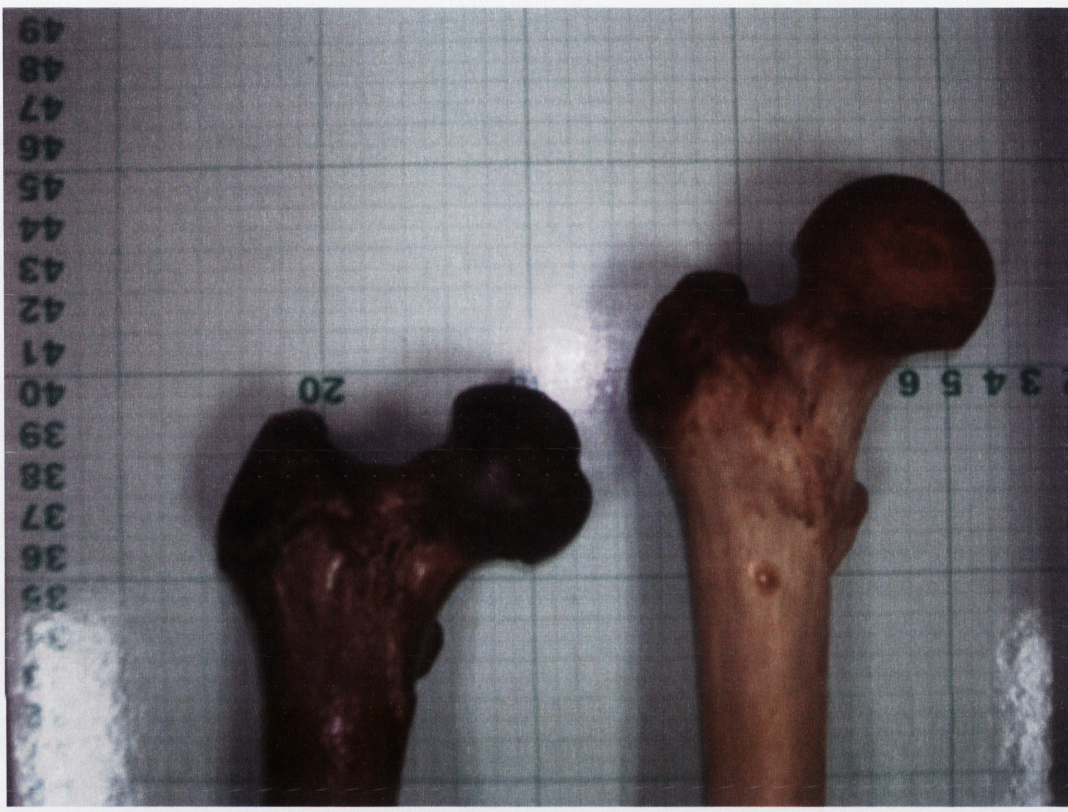
Extensive damage to a distal femoral epiphysis, preventing measurement of the MFL, BCB, AP80, ML80, AP50 and ML50 variables



The extent of NSA variation in the Bangkok sample was marked (e.g., Figure 13), with a range of 22°, illustrating the need for extensive geographical sampling (and adequate sample sizes) in order to investigate any possible trends in average NSA between human groups in different climatic zones.

Figure 13

NSA variation in the Bangkok sample



Findings

For the NSA, the frequency distribution of scores approximates a normal distribution around the mean, 126.0° (Figure 14). Descriptive statistics are shown in Table 4; notable is the failure to detect significant gender or side differences in this sample. Descriptive statistics for the other variables are given in Table 5.

Figure 14

Frequency distribution of Bangkok NSA scores

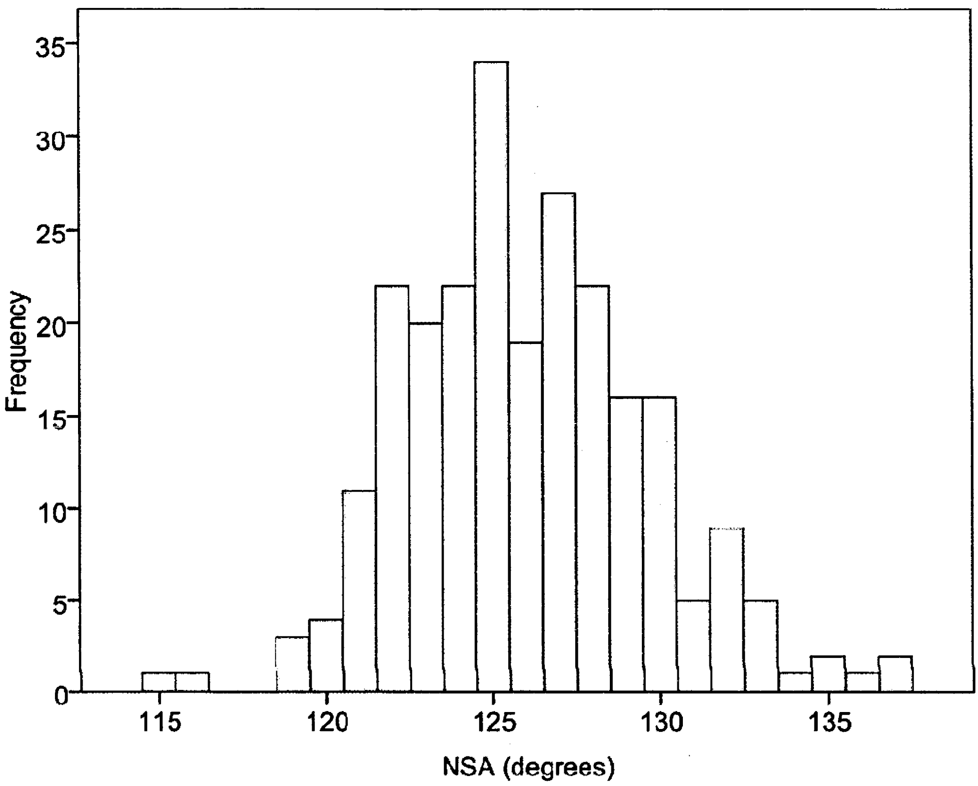


Table 4

Descriptive statistics for Bangkok NSA

	n	*minimum*	*maximum*	*mean*	*SD*
NSA	243	115°	137°	126.0°	3.65°
Gender	137				
Male	95	116°	137°	126.4°	3.88°
Female	42	122°	136°	126.3°	3.32°
Side	243				
left	124	119°	137°	125.9°	3.36°
right	119	115°	137°	126.1°	3.94°

Table 5

Descriptive statistics for other variables

Variable	*n*	*minimum*	*maximum*	*mean*	*SD*
MFL	243	358	491	424.3	25.35
FHD	240	35.1	54.9	43.7	3.68
AP80	243	19.5	33.0	26.3	2.69
ML80	243	22.6	37.2	29.8	2.76
AP50	243	21.2	34.8	27.4	2.49
ML50	243	19.3	31.2	25.2	2.19
BCB	223	62.9	88.3	76.7	6.04

Outcomes

Aside from assessing the practicalities of global sampling of the femoral NSA among modern human groups, and so facilitating the planning of institution visits and the setting of priorities, the value of this pilot study was proven by the discovery that measurement of the NSA on an osteometric board (as initially planned) is highly inaccurate due to varying anteversion of the femoral neck. The use of a hand-held goniometer renders the procedure comparatively simple, and is usually associated with acceptably small intra-observer errors of 0°-2° (Trinkaus 1993, pp. 397-398). In relation to results, the finding of very substantial variation in the NSA (22°), even within this one sample derived from a reasonably localized population, underscores the need for adequate sampling (in terms of both geographical coverage and sample sizes) in order to meet the aims of this research study.

Chapter 5: Preliminary Analysis

The preliminary analysis is limited essentially to the presentation of primary data obtained from the extensive global survey of the NSA among modern human groups (Gilligan in press), and a discussion of results from an exploratory statistical analysis of the findings in relation to climatic indices (latitude, mean annual temperature, and mean summer and winter temperatures).

Aims

Once collection of femoral data was completed, the data files were checked and then re-assembled into appropriate sample groups, as many of the individual samples derived from multiple institutions. The initial analysis is aimed at matching the group NSA means to the main independent variables of interest (namely, climatic indices) and examining for possible large-scale (i.e., global) patterning of the NSA findings in relation to these indices. Further analyses in subsequent chapters examine the data for more detailed trends (at the continental and regional levels), and also for possible relationships between the NSA and other independent variables (e.g., patterns of clothing use, economic and mobility categories) as well as examining for trends and relationships among the other femoral variables—MFL, FHD, BCB and the shaft shape variables. In addition, anatomical questions regarding variation in the human NSA are later addressed utilizing this extensive database, in regard to possible gender and side differences and whether the NSA declines with advanced age.

Materials and Method

The femoral data in this preliminary analysis comprise only the mean NSA scores for each sample; the complete database, which lists all the data for each femur (including provenance and scores on additional femoral measures), is provided in Appendix A3, and the mean group NSA scores together with sample size (*n*) and minimum, maximum and standard deviation (SD) values are listed in Appendix A4.

Femoral Samples

Skeletal collections of modern human femora were selected on the basis of measurable NSA; complete or largely intact femora comprise the majority, although a substantial proportion of the remainder consist of proximal segments with sufficient portions of the neck and shaft preserved to permit measurement of the NSA. Specimens with obvious deformity or pathology (such as Paget's Disease, or remodeled neck fractures) were excluded; neither juvenile nor early adolescent bones lacking epiphyseal fusion were examined. Depending on the extent of preservation or completeness, other measures were taken: maximum femoral length (MFL), femoral head diameter (FHD), anterior-posterior and medio-lateral shaft diameters (at the subtrochanteric and mid-shaft levels (AP80, ML80, AP50, ML50), and bicondylar breadth (BCB); side (left or right) was recorded, as well as gender and age at death (where available)—only the NSA data are discussed in this chapter. Measurements of the NSA were taken with a plastic 360° goniometer.

Given that a primary purpose of this research was to obtain a useful sampling of NSA among human groups from a diverse range of environments, the quest to maximize sample size was balanced by the need for broad sampling. In some cases, very small samples were included—even a single femur from a certain locality might be measured at one institution, as this could then be added to other samples from the same or a similar locality at other institutions or combined with larger groups or regional samples in subsequent analyses. Given the requirement to be able to link each sample with geographical location and hence climatic indices, provenance to country of origin was a priority in determining inclusion—the main exceptions relate to specific human groups (such as Bushmen, Sami and central African Pygmies) where associations with modern national entities are less relevant. The numbers of femora measured and numbers of countries or groups sampled at each institution are listed in Tables 6 and 7, and the global distribution of samples is shown in Figure 15. The data were collected during six months (24 weeks) of fieldwork between 2007 and 2008; the dates of the visits to each institution are shown in Appendix A5.

A total of 8,271 femora were measured. When grouped according to country (or territory) of origin, the total number of samples is 101 (80 countries, 10 territories and 11 other groups). Multiple regional samples were obtained for two countries (10 state samples from the U.S.A., and 21 provincial samples from France), but this preliminary analysis is restricted to the 101 basic samples. One of the samples (from the Cote d'Ivoire) comprises only a single femur, which is included in some of the subsequent analyses as part of the African continental sample, but is excluded from the statistical analyses which utilize group means, yielding a net sample size of 100 countries/territories/other groups.

Figure 15

Distribution map of NSA samples (the basic 101 samples, with the U.S.A. shown as eight state sub-samples in addition to Alaska and Hawaii)

Table 6

Femoral sample sizes (n) listed alphabetically by participating institution, and number of countries, territories and other groups sampled

Institution	*Location*	*N*	*Countries*	*Other Territories*[1]	*Other Groups*[2]
American Museum of Natural History (AMNH)	New York NY, U.S.A.	436	9	3	5
Chiang Mai University Medical School (CMU)	Chiang Mai, Thailand	214	1		

Congdon Anatomical Museum(CAM)	Bangkok, Thailand	243	1		
Florida Museum of Natural History (FLMNH)	Gainesville FL, U.S.A.	306	1		
Institut de Paléontologie Humaine (IdPH)	Paris, France	255	5		1
Leverhulme Centre for Human Evolutionary Studies (LCHES)	Cambridge, England	350	5		4
Museé de l'Homme (MdlH)	Paris, France	2307	60	6	5
National Museum of Nature and Science (NMNS)	Tokyo, Japan	331	1		
Natural History Museum (NHM)	London, England	1991	12		6
Peabody Museum, Harvard University (PM)	Boston MA, U.S.A.	281	8	1	1
Sapporo Medical University (SMU)	Sapporo, Japan	172	1		2
Smithsonian Institution (SI)	Washington DC, U.S.A.	1338	14	3	3
South Australian Museum (SAM)	Adelaide, Australia	47	1		

Notes: 1. Certain territories are listed independently of the countries responsible for their administration, e.g., Canary Islands (Spain), Easter Island (Chile), Greenland (Denmark), Guadeloupe (France), Guam (U.S.A.), Marquesas Islands (France), Nicobar Islands (India), and Tahiti (France); *2.* Some groups are listed separately from their geographical or national associations, e.g., Ainu (Japan), Andaman Islanders (India), Bushmen (also known as !Kung or San peoples, southern Africa), Fuegians (southern South America), Inuit (Alaska), Moriori (Chatham Island, New Zealand), Negritos (Philippines), Okhotsk (Hokkaido, Japan), Pygmy groups (central Africa), Sami (formerly known as Lapps, northern Scandinavia and northeastern Russia), and Veddahs (Sri Lanka).

Table 7

Sample sizes (*n*) for each of the 101 countries/territories/groups. For statistical purposes, the one sample comprising a single femur (Cote d'Ivoire) is excluded from subsequent analyses, resulting in a total of 100 samples

Continent / Region	*n*	*Country*	*n*	*Territories*	*n*	*Other Groups*	*n*
Africa	1155						
		Algeria	53				
		Angola	11				
		Benin	10				
		Central African Rep.	5				
		Chad	10				
		Congo	6				
		Cote d'Ivoire	1				
		Egypt	136				
		Equatorial Guinea	2				
		Ethiopia	5				
		Gabon	25				
		Gambia	2				
		Ghana	2				
		Guinea	2				

		Madagascar	62				
		Mali	53				
		Morocco	59				
		Mozambique	10				
		Niger	43				
		Nigeria	2				
		Senegal	8				
		Somalia	47				
		South Africa	34				
		Sudan	130				
		Tanzania	161				
		Tunisia	2				
				Canary Islands	223		
						Bushmen	35
						Pygmy	16
Asia	1463						
		Bangladesh	2				
		China	115				
		India	47				
		Indonesia	11				
		Iran	6				
		Japan	251				
		Kampuchea	2				
		Laos	2				
		Malaysia	5				
		Nepal	2				
		Pakistan	4				
		Philippines	92				
		Sri Lanka	16				
		Syria	15				
		Thailand	457				
		Turkmenistan	4				
		Vietnam	16				
				Nicobar Islands	12		
				Russia (Siberia)[3]	18		
						Ainu	233
						Andamans	81
						Negrito	37
						Okhotsk	19
						Veddah	16
Australia	47						

		(South) Australia	47				
Europe	2799						
		Armenia	2				
		Belgium	6				
		Cyprus	2				
		Czech Republic	56				
		England	1271				
		Estonia	4				
		Finland	2				
		France	768				
		Iceland	146				
		Italy	10				
		Norway	4				
		Poland	8				
		Russia	46				
		Scotland	434				
		Spain	14				
		Sweden	2				
		Ukraine	10				
		Wales	2				
						Sami	12
North America	1766						
		Canada	272				
		Dominican Republic	24				
		Mexico	65				
		U.S.A.	987				
				Greenland	90		
				Guadeloupe	4		
						Inuit	324
Pacific	332						
		Fiji	3				
		Kiribati	4				
		New Zealand	20				
		Papua New Guinea	59				
		Solomon Islands	20				

		Tonga	4				
		Vanuatu	76				
				Easter Island	94		
				Guam	2		
				Hawaii[4]	12		
				Marquesas	2		
				Tahiti	11		
						Moriori	25
South America	709						
		Argentina	108				
		Bolivia	33				
		Brazil	9				
		Chile	49				
		Ecuador	193				
		Peru	211				
		Surinam	4				
		Venezuela	68				
						Fuegian	34

Notes: 3. the Russian Far East (a Russian federal district formerly known loosely as Siberia) is here considered separately as part of the continent of Asia rather than Europe; *4.* Hawaii, though a state of the U.S.A., is listed separately in the Pacific region.

Climatic Indices

Ideally, the optimal indices for assessing potential global patterning of the NSA in relation to climatic variation would include those meteorological variables that have the greatest significance for human thermoregulation and so might be expected to exert the most selection pressure in terms of morphological adjustment.

In particular, seasonal extremes (e.g., summer maximum and winter minimum temperatures) and winter wind chill estimates would provide the best opportunity for detecting any climatic influences on the NSA. These indices are available from meteorological records in a few parts of the world (Australia, for instance, and most of North America and Western Europe), but the records from many other parts of the world are very limited. The climatic analyses require uniform indices across all of the sample groups, and this is determined essentially by the quality of meteorological data in locations with minimal records. Latitude can be assigned to each sample as a simple climate proxy, but only annual and monthly average temperatures are available from weather stations in every part of the world covered by the NSA database. In this study, therefore, each sample was assigned a local weather station with adequate meteorological records to provide (in addition to latitude) three climatic indices:

1. Annual mean temperature (°C);
2. Summer mean monthly temperature (°C); and
3. Winter mean monthly temperature (°C).

A number of internet websites offer well-sourced meteorological data on these indices for thousands of locations worldwide; the Weatherbase^{SM} site (www.weatherbase.com) was chosen for these analyses. For each of the samples, the selected weather station, latitude and temperature data are listed in Table 8. The selected weather station is typically the designated capital city (or, in the case of the Andaman Islands for instance, the recognized administrative centre) of the country/state/territory. Latitude is that of the weather station, with climate data comprising mean annual temperature (A), and mean January or July monthly temperatures (°Celsius) for summer (S) and winter (W), depending on hemisphere.

Table 8

List of each sample group (and mean NSA) with the assigned latitude and the associated climatic data from Weatherbase[SM]

Groups	*NSA*	*Weather Station*	*Latitude*	*A*	*S*	*W*
AFRICA						
Algeria	123.4	Algiers	37	17	25	11
Angola	128.7	Luanda	9	24	25	20
Benin	130.1	Porto-Novo	6	26	25	27
Canary Islands	125.7	Las Palmas	28	20	23	17
Central African Rep.	128.2	Bangui	4	26	25	24
Chad	132.3	N'jamena	12	28	28	23
Congo	123.7	Kinshasa	4	26	26	23
Cote d'Ivoire	128.0	Yamoussoukro	7	26	25	26
Egypt	127.0	Cairo	30	21	28	13
Equatorial Guinea	127.0	Malabo	4	25	24	24
Ethiopia	132.2	Addis Ababa	9	16	15	16
Gabon	130.0	Libreville	0	26	27	24
Gambia	144.0	Banjul	13	26	27	23
Ghana	125.5	Accra	6	27	25	27
Guinea	133.5	Conakry	10	27	25	26
Madagascar	126.1	Antanarivo	19	18	21	15
Mali	130.8	Bamako	13	28	26	25
Morocco	120.0	Rabat	34	17	22	12
Mozambique	120.8	Maputo	26	23	27	19
Niger	129.0	Niamey	13	29	28	24
Nigeria	129.5	Abuja	9	23	25	28
Senegal	132.5	Dakar	15	24	27	21
Somalia	125.5	Mogadishu	2	27	26	27
South Africa	129.7	Pretoria	26	18	23	12
Sudan	130.5	Khartoum	16	30	32	23
Tanzania	127.8	Dodoma	6	22	23	19
Tunisia	125.5	Tunis	37	18	26	11

ASIA						
Bangladesh	126.0	Dhaka	24	26	28	19
China	127.2	Beijing	40	12	26	-3
India	129.9	Delhi	29	25	30	14
Indonesia	131.6	Jakarta	6	27	26	27
Iran	125.2	Tehran	36	17	31	1
Japan	127.2	Tokyo	36	15	25	5
Kampuchea	127.5	Phnom Penh	12	27	28	26
Laos	129.0	Vientiane	18	26	28	22
Malaysia	132.8	Kuala Lumpur	3	27	27	27
Nepal	128.0	Kathmandu	28	18	23	10
Nicobar Islands	131.6	Port Blair	12	27	27	26
Pakistan	126.3	Islamabad	34	21	29	10
Philippines	128.6	Manila	15	27	27	26
Siberia	130.0	Vladivostok	43	5	17	-12
Sri Lanka	129.7	Colombo	7	27	28	27
Syria	125.3	Damascus	33	16	26	6
Thailand	127.5	Bangkok	14	28	29	26
Turkmenistan	121.5	Ashgabat	38	16	30	5
Vietnam	126.3	Hanoi	21	24	30	16
AUSTRALIA						
(South) Australia	130.2	Adelaide	35	16	21	11
EUROPE						
Armenia	128.5	Yerevan	40	12	26	-2
Belgium	125.3	Brussels	51	10	17	3
Cyprus	118.5	Nicosia	35	18	28	9
Czech Republic	126.8	Prague	50	8	17	-1
England	125.5	London	51	10	16	3
Estonia	126.0	Tallinn	59	5	16	-3
Finland	121.5	Helsinki	60	5	16	-5
France	127.0	Paris	49	11	19	3
Iceland	126.6	Reykjavik	64	4	11	-1
Italy	127.7	Rome	42	15	23	8
Norway	126.0	Oslo	60	6	17	-3
Poland	125.3	Warsaw	52	8	17	-1
Russia	126.0	Moscow	56	4	17	-8
Scotland	127.7	Edinburgh	56	8	15	3
Spain	124.2	Madrid	40	13	24	5
Sweden	122.0	Stockholm	60	6	17	-2
Ukraine	124.8	Kiev	50	7	18	-6
Wales	125.5	Cardiff	51	10	16	5
NORTH AMERICA						
Canada	124.2	Ottawa	45	6	21	-10

Dominican Republic	124.3	Santo Domingo	18	26	27	24
Greenland	129.3	Nuuk	64	-1	7	-8
Guadeloupe	120.8	Basse-Terre	16	26	27	24
Mexico	126.5	Mexico City	19	17	18	13
U.S.A.	125.6	Washington	39	14	26	2
PACIFIC						
Easter Island	126.7	Hanga Roa	27	21	23	18
Fiji	133.3	Suva	18	24	26	23
Guam	128.5	Hagatna	13	27	27	26
Hawaii	132.9	Honolulu	21	25	26	22
Kiribati	128.3	Tarawa	1	28	28	28
Marquesas	126.0	Atuona	10	26	27	25
New Zealand	124.3	Wellington	41	12	17	8
Papua New Guinea	132.0	Port Moresby	9	27	27	25
Solomon Islands	132.4	Honiara	9	26	27	26
Tahiti	132.5	Papeete	18	26	26	25
Tonga	129.5	Nuku'alofa	21	23	25	21
Vanuatu	130.9	Port Vila	18	24	26	22
SOUTH AMERICA						
Argentina	128.9	Buenos Aires	35	16	23	10
Bolivia	117.6	Sucre	19	15	16	13
Brazil	128.1	Brasilia	16	21	22	18
Chile	124.5	Santiago	33	14	21	8
Ecuador	125.9	Quito	0	14	14	14
Peru	122.2	Lima	12	20	23	17
Surinam	127.3	Paramaribo	5	27	27	26
Venezuela	127.0	Caracas	11	23	23	21
OTHER GROUPS						
Ainu	125.3	Sapporo	43	8	21	-5
Andaman Islands	136.1	Port Blair	12	27	27	26
Bushmen	126.7	Gaborone	25	21	26	13
Fuegian	122.4	Punta Arenas	53	6	10	1
Inuit	120.2	Juneau	58	5	13	-4
Moriori	130.9	Waitangi	44	10	14	7
Negrito	130.9	Manila	15	27	27	26
Okhotsk	124.8	Sapporo	43	8	21	-5
Pygmy	131.6	Kinshasa	4	26	26	23
Sami	125.3	Helsinki	60	5	16	-5
Veddah	132.3	Colombo	7	27	28	27

Analyses

Pearson correlation coefficients were calculated on the mean NSA for each of 100 samples. The four environmental variables are latitude, mean annual temperature, and two seasonal means (summer and winter). Tests were carried out with SPSS® Graduate Pack 16.0 for Windows. The null hypotheses generally involve explicit directional trends (e.g., that the NSA is not significantly *lower* in cooler climates), hence one-tailed tests are justifiable. Significance levels are adjusted for multiple testing — although such "adjustemts" may be criticized on theoretitcal grounds (e.g., Perneger 1998). With four environmental variables, a Bonferroni correction gives 0.05 ÷ 4 = 0.0125 (rounded down to 0.01). Unless indicated otherwise, one-tailed tests with a significance level of 0.01 are used in all subsequent analyses.

Results

Before examining for any climatic trends in the NSA at a global level, the mean NSA for the entire sample and the distribution of NSA scores is presented.

Mean Global NSA

Two methods exist for calculating the global mean NSA: the first uses the total number of individual femora (n = 8271), and the second uses mean NSA scores for the group samples (n = 100). The mean NSA scores are 126.4° and 127.4°

respectively; descriptive statistics are shown in Table 9, and the NSA scores for individual femora are plotted (against a normal distribution curve) in Figure 16.

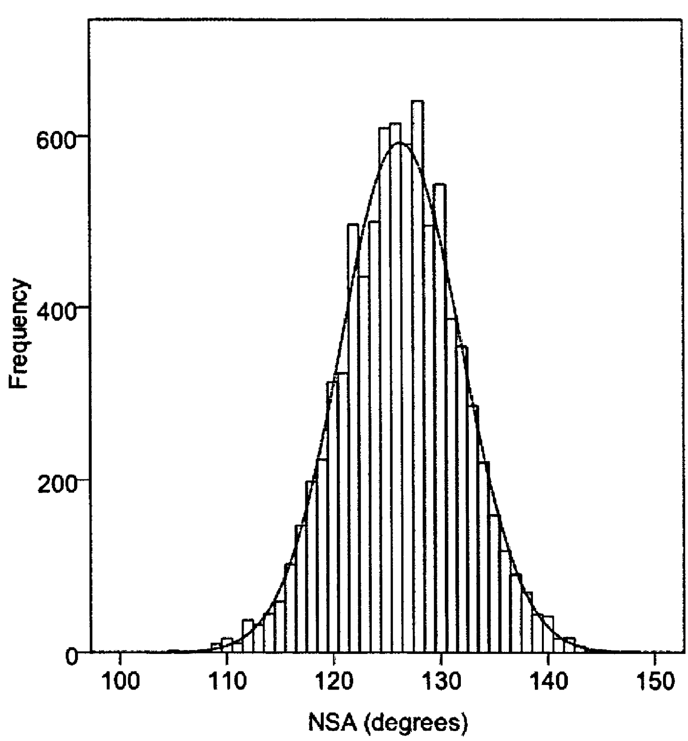
Table 9

Descriptive statistics for the global NSA based on the whole NSA database

Sample	*n*	*Mean*	*Minimum*	*Maximum*	*SD*
Total femora	8271	126.4	105	148	5.57
Group samples	100	127.4	117.6	144.0	3.92

Figure 16

Frequency distribution of the NSA in the global sample (n = 8271)



Climatic Trends in the Global NSA

Table 10 shows the Pearson correlation coefficients (*r* values) between NSA and the four environmental indices, together with the results of significance tests and the r^2 value (which estimates the proportion of variance in NSA that may be attributed to each environmental variable). The results are shown as scatterplots for NSA against each of the four environmental indices in Figures 17 to 20.

Table 10

Climate results for 100 NSA samples: Pearson correlation coefficients (*r*) for latitude and the climate variables, significance level of the result (2-tailed tests), and an estimate (r^2) of total variance (%) in the NSA attributable to these variables

Variable	*n*	*r*	*Significance (* p < .01)*	r^2
Latitude (°N/S)	100	-.430	<.001*	18.5%
Annual mean temperature (°C)	100	+.457	<.001*	20.9%
Summer mean monthly temperature (°C)	100	+.300	.001*	9%
Winter mean monthly temperature (°C)	100	+.461	<.001*	21.3%

Figure 17

Scatterplot of Pearson correlation results for NSA and latitude

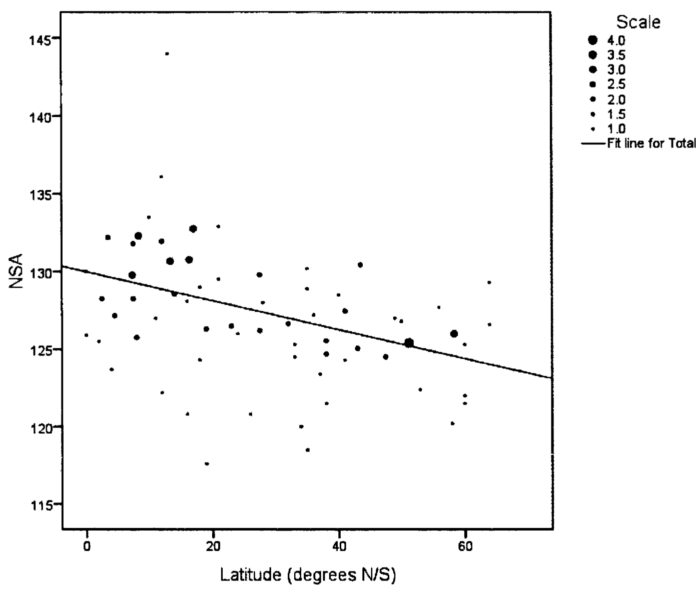


Figure 18

Scatterplot of Pearson correlation results for NSA and mean annual temperature

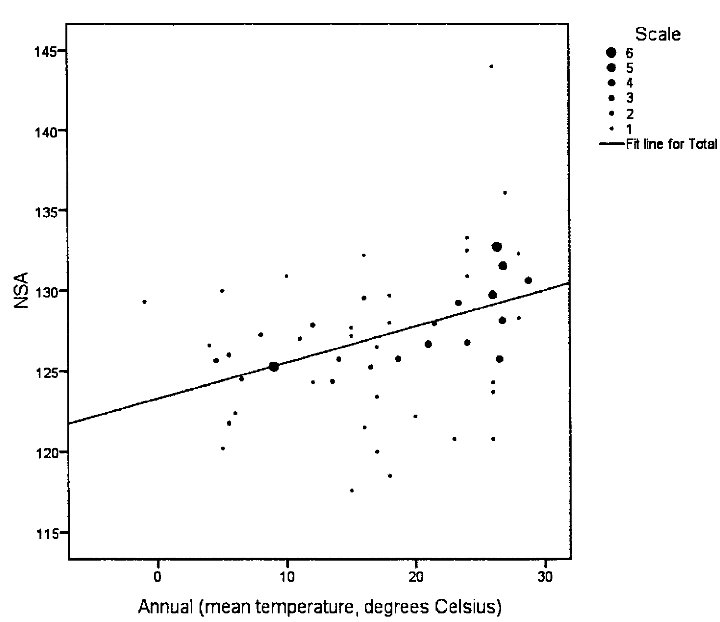


Figure 19

Scatterplot of Pearson correlation results for NSA and mean summer temperature

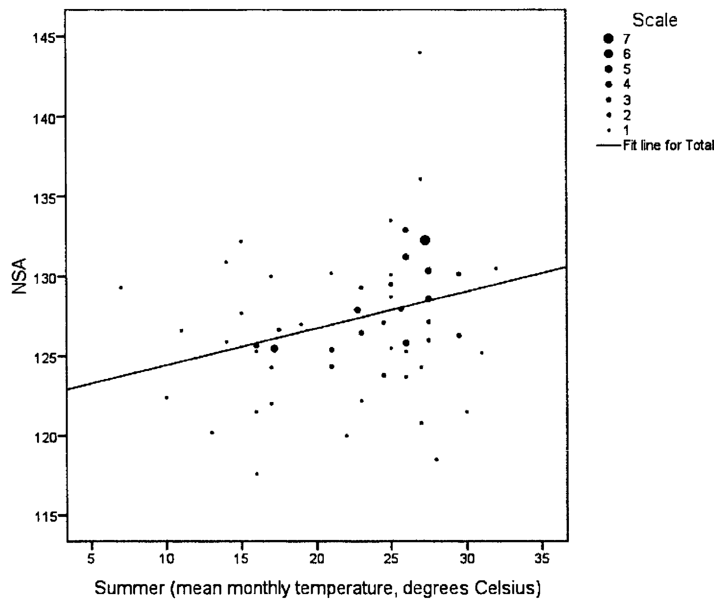
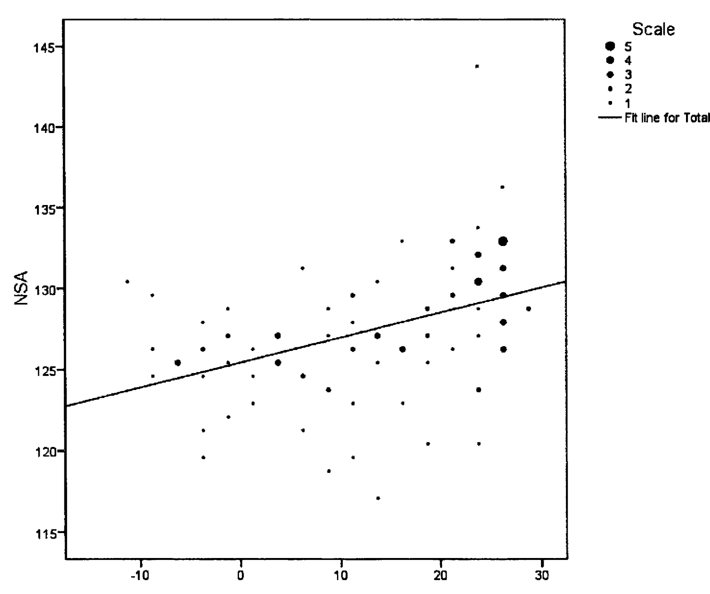


Figure 20

Scatterplot of Pearson correlation results for NSA and mean winter temperature



All correlations are significant at the .01 level (all except the summer variable having $p < .001$), with winter mean monthly temperature yielding the highest r value. While r^2 values are modest (~ 20% for latitude, annual and winter temperature), these results suggest that the observed associations between NSA and environmental variables are anthropologically (as opposed to merely statistically) significant, given the variability in NSA even within small samples.

Discussion

The findings shown here on the femoral NSA in modern humans confirm the high magnitude of its variation at the global and group levels, underlining the need to ensure both a wide geographic spread of samples and inclusion of adequate sample sizes before making generalizations as to any patterning or trends that may exist in its variation. The total database of 8,271 femora indicates a "global" NSA mean of 126.4° with a range of 43°, while the 100 group samples yield a mean of 127.4° and a range of 26.4°. Within the larger group samples, the NSA ranges up to approximately 30°, a figure which far exceeds any likely mean differences at a population level. For example, in the largest country sample (England, n = 1271), the NSA varies from a minimum of 108° to a maximum of 142°, a range of 32°; similarly, the U.S.A. samples (n = 987, excluding Alaska and Hawaii) have a 33° range, the French samples (n = 768) a range of 30°, and likewise the Canary Islands (n = 223, range 30°). Within-group variation is not uncommonly between around 20° and 30° even in smaller samples, e.g., Madagascar (n = 62, range 22°), China (n = 115, range 26°), Sudan (n = 130, range 25°), Philippines (n = 92, range 28°), Vietnam (n = 16, range 25°), and Chile (n = 49, range 31°).

This extensive NSA database is unique not only in terms of its total size and the extent of group sampling and geographical coverage, it also has the benefit of the data deriving from measurements taken by a single observer using a hand-held goniometer on the femora themselves. This minimizes the confounding effect of femoral anteversion in determining NSA and avoids the perils of pooling data from other published sources where techniques may differ substantially (and, in many cases, where the measurements have been taken on radiographs).

In terms of geographical and climatic patterning evident in the data, the results presented in this chapter are limited to a preliminary overview at the global level to ascertain the likelihood of large-scale trends in mean NSA values. The findings certainly suggest that, notwithstanding the high variability within groups and the small sample sizes in many samples (36—approximately one third—of the 101 groups containing fewer than 10 femora), the breadth of sampling reveals an overall significant trend of lower NSA in cooler environments among modern human groups.

The database clearly lends itself to further analytic exploration with more sophisticated methods which may allow other questions to be addressed and enable more complex relationships to be disentangled. Nonetheless, it would appear for example that geographical and climatic patterning exists in the NSA at the regional and continental levels, in addition to the global trend that emerges in the present analysis. Within Africa, not only are the mean NSA values generally higher than for other continents, most of the higher NSA means are found within the tropics (e.g., Chad 132.3°, Ethiopia 132.2°, Gabon 130.0, Guinea 133.5°, Mali 130.8°, Senegal

132.5°, and Sudan 130.5°). The highest mean NSA in the whole database is from Gambia (144.0°), but this is from a very small sample (n = 2). Most of the lower mean NSA values in Africa occur in cooler parts of the continent (e.g., Algeria 123.4°, Morocco 120.0°, Mozambique 120.8°). The regional trends in eastern Asia, the Pacific and North and South America appear less prominent but are similarly suggestive. Skeletal sampling from Australia was limited to a single sample in South Australia (n = 47), from Roonka Flat where the burials date mainly to the mid-late Holocene (Pate 2006, Robertson and Prescott 2006). The mean NSA of 130.2° for the Roonka sample is in the higher range on a global scale, as might be expected, and is moderately higher than the only previously published mean NSA for Australian Aborigines (Davivongs 1963) of 127.8°.

Of special anthropological interest are the NSA results for the 11 "other groups" where the data are presented separately from countries and territories. Among these, the lower NSA values tend again to occur in cooler environments (e.g., Inuit—in this instance, the term Aleutian might be less inaccurate, as the samples derive from the Aleutian archipelago in Alaska—120.2°, Fuegian 122.4°, Okhotsk 124.8°, and the Ainu and Sami 125.3°), while higher NSA values generally occur among those groups inhabiting warmer regions (e.g., Andaman Islanders 136.1°, Veddah 132.3°, central African Pygmies 131.6°, and Philippine Negritos 130.9°).

Limitations

There are obvious limitations in this preliminary analysis, some of which are addressed in the subsequent analyses. Firstly, these results have utilized relatively simple climatic indices—latitude, mean annual temperature, and mean monthly summer and winter temperature. Surprisingly, given that latitude is at best a crude approximation for average thermal conditions, a global NSA trend has emerged on this variable (and the correlation is statistically significant). Not surprisingly, mean annual temperature yields a stronger climatic association, and one of the seasonal variables (winter) yields the highest correlation. Nevertheless, more sophisticated meteorological indices—such as average maximum and minimum temperatures and, ideally, the more physiologically meaningful indices of thermal stress such as wind chill and apparent temperature (e.g., Steadman 1984, Quayle and Steadman 1998)—would provide better measures of the local thermal environments. As discussed above, this is not feasible given the lack of suitable indices from most of the locations, although the following analyses benefit from a revised selection of weather stations.

The major shortcoming that must be addressed, however, is the need to control for some of the non-environmental variables that have been claimed in other studies to influence variation in the NSA among human groups. Of these, the most salient relates to habitual activity levels and degree of mobility in different population samples. As discussed above, a number of the earlier studies have attributed a greater role for these activity factors in NSA variability than climate (e.g., Trinkaus 1993, Anderson and Trinkaus 1998), although the debate is far from resolved (e.g., Weaver 2003). With respect to the NSA database presented here, there is evidently scope to investigate this issue by examining the data in relation to additional sample categories, for instance by dividing the groups according to lifestyle (e.g., forager, agricultural, and urban). Another factor that should be taken into account, given the major aim of exploring whether greater "cultural buffering" from the thermal environment may exert an influence on patterns of morphological variation, is the extent to which the various population groups sampled here employ thermally-effective clothing on a regular basis.

Cultural Buffering

The significance of cultural buffering—mainly, though not limited to, the habitual use of clothing—is that, as a behavioural adaption to the thermal environment, it might be expected to exert an ameliorating effect on the development of morphological adaptations, and vice versa (e.g., Gilligan 2007a, 2007b). Such interactions between biological and behavioural adaptations may affect the extent to which clothing is required as thermal protection, among other repercussions (e.g., Gilligan 2007c, 2007d, 2007e). Furthermore, the regular use of clothing may also act as a confounding variable in assessing the possible role of mobility on the NSA. The reason this may be the case is that the lifestyle categories commonly used to classify levels of habitual activity—forager, agricultural, and urban (e.g., Anderson and Trinkaus 1998, p. 284)—may themselves be associated systematically with differing levels of clothing use. Foragers such as the Australian Aborigines typically wore no clothing, and its use appears to relate exclusively to minimal thermal requirements (Gilligan 2008). The Andaman Islanders and Fuegians are other examples, while the advent of agricultural practices—in terms of the evidence from prehistoric archaeology—is associated with a marked focus on the production of clothing, especially thermally-efficient textile garments (Gilligan 2007c). Similar trends in patterns of clothing use are apparent among early Holocene foragers who adopted a more sedentary lifestyle, with or without agricultural, horticultural or pastoralist activities, while those communities that developed a fully urban lifestyle were likewise characterized by the regular use of clothing. In other words, the categories that have been employed to distinguish differing levels of mobility or habitual activity may also distinguish differing levels of habitual clothing use, which might create a thermal basis for any apparent trends in the NSA between these groups.

Despite its limitations, the data on the NSA among human groups and the preliminary environmental analyses presented here document considerable variation in this morphological parameter both within and between groups, variation which nonetheless manifests an overall association with geographical variation in average temperature regimes. To this extent, the NSA may vary in concert with other aspects of human morphology—notably body shape—which show environmental patterning as a reflection of thermally adaptive influences. Further analyses and refinements in methodology may be expected to clarify these findings and address some of the unresolved questions that surround the NSA, which may shed light on aspects of the interaction between biological and behavioural adaptations among modern humans.

Chapter 6: Further Climate Analyses

Before examining the possible role of lifestyle variables (mobility and economy) and the use of clothing in NSA variation, the global climatic patterning revealed in the last chapter should be explored in more detail. With the exception of Australia (which is represented only by the single small sample from Roonka), the database includes reasonably extensive coverage at the continental level. In addition, the large samples from two countries (the U.S.A. and France) include multiple sub-groups provenanced to local regions, allowing for the exploration of possible climatic relationships at a more refined level.

Continental Means and Trends

Continental Means

The mean NSA figures from each of the continents—counting the Pacific as a "continent"—are presented in Table 11 and Figure 21. Each of these continental means is calculated in two ways: first, using the individual NSA of each femur (that is, independent of the countries, territories and other groups) and, second, using the group means. The only continent where the resulting mean NSA values differ to any extent is Europe, where approximately half of the continental NSA derives from a single large sample (the Poundbury sample from England), and that difference is small (1°).

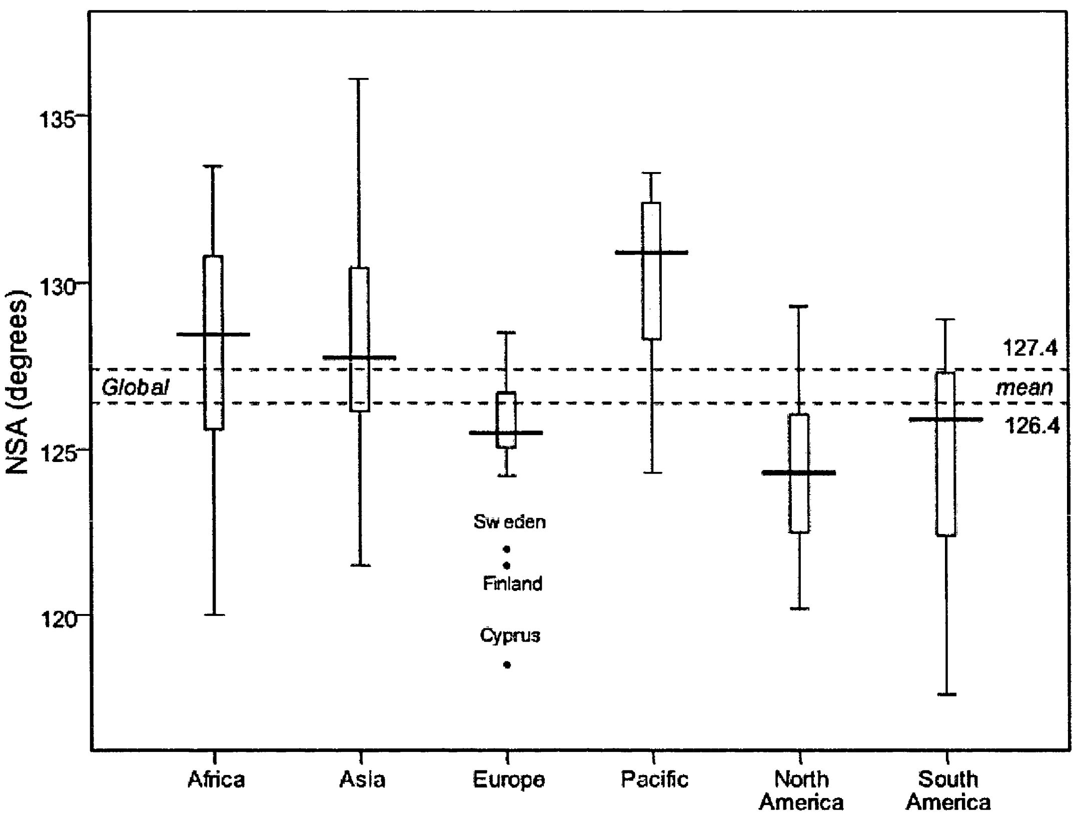
Table 11

Continental mean NSA values, calculated on both the total femoral samples and on the group NSA means

Continent	*n*	*Mean*	*Minimum*	*Maximum*	*SD*
Africa					
total	1155	127.2	110	145	5.72
samples	28	128.5	120	144	4.60
Asia					
total	1463	128.8	112	148	5.31
samples	23	128.5	122	136	3.29
Europe					
total	2799	126.3	108	142	5.32
samples	19	125.3	119	129	2.39
North America					
total	1766	124.6	109	142	5.38
samples	7	124.4	120	129	3.18
Pacific					
total	332	129.6	115	143	4.99
samples	13	129.9	124	133	2.91
South America					
total	709	124.7	105	144	5.81
samples	9	124.9	118	129	3.61

Figure 21

Continental distributions of mean NSA (100 group means)



The highest NSA mean is found in the Pacific, with high values also in Africa and, to a lesser degree, Asia; lower continental means are found in the Americas, with Europe occupying an intermediate position. Even at this gross level, it is possible to suggest that these continental differences could reflect the differing thermal environments (and the environmental histories) of the populations. The Pacific samples comprise approximately half Melanesian and half Polynesian groups (Micronesia being represented only by two very small samples, from Kiribati and Guam). Melanesians have a long history (and prehistory extending at least into the late Pleistocene) in the tropics while the Polynesians have their mid-Holocene origins in Melanesia and southeastern Asia. The reasonably high African mean is expected given that tropical and subtropical parts of the continent are well represented. The similar Asian mean may result from a majority (14/24) of the samples deriving from the tropics, with only a quarter (6/24) deriving from cooler temperate environmental zones—China (a single Smithsonian sample provenanced loosely to northern China), Japan, Nepal, the Russian Far East and the Ainu and Okhotsk groups). An extensive use of thermally-effective clothing among most if not all of these latter six groups might ameliorate any climatic influence: all have relatively high NSA values (the Russian Far East—formerly known as Siberia—having the highest, 130°), with the exception of the Okhotsk (mean NSA 124.8°) and, to a lesser extent, the Ainu (125.3°) groups. Relatively lower NSA group means in Europe are expected on thermal grounds, as is a narrower NSA range compared to other continents, reflecting the more restricted geographical range in terms of latitude (and hence a more restricted range of temperatures). While the Cyprus outlier is anomalous in this context, it may represent an unreliable mean population estimate given the very small sample size (n = 2), whereas the two Scandinavian outliers are consistent with thermal expectations.

The lower NSA means for the Americas are of interest in terms of a likely climatic influence, given the late Pleistocene origins of the Native American populations in northeastern Asia. Even with archaeological evidence for the use of complex clothing among the early immigrants to the New World (discussed in Appendix 2), a degree of climatic selection for morphological cold adaptations among the ancestors of Native Americans in polar regions at the end of the last ice age is not unexpected.

Continental Climate Trends

The group mean NSA values on each continent are analyzed here in relation to the climatic indices, to examine for the existence of climatic trends in NSA at the continental level.

Africa

Pearson correlations between group NSA and the climate variables (and the results of significance tests) for the 28 African groups are shown in Table 12. The correlations are modest but nonetheless follow anticipated climatic trends (negative for latitude, positive for temperature), although none quite reach the 0.01 (adjusted) significance level. The results for mean winter temperature are plotted in Figure 22.

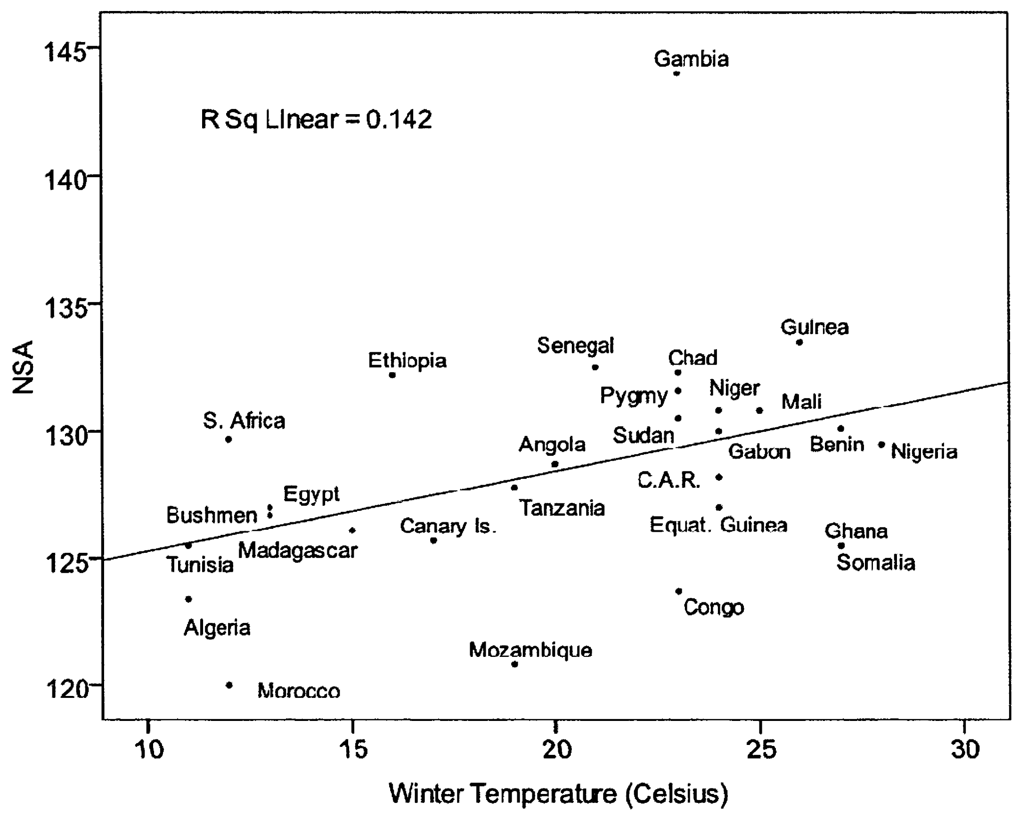
Table 12

NSA and climate correlations for Africa

Climate Variable / Proxy		*n*	*r*	*Significance (*p < .01)*
L	Latitude (°N/S)	28	-.381	.045
A	Annual mean monthly temperature (°C)	28	+.390	.020
S	Summer (July) mean temperature (°C)	28	+.140	.239
W	Winter (January) mean temperature (°C)	28	+.377	.024

Figure 22

Scatterplot of NSA and winter temperature for Africa



The very small (n = 2) sample from Gambia emerges as an outlier with its high NSA of 144° but, even so, the distribution of these African group means follows an overall trend with winter temperature. Morphological adaptation to seasonal temperature variation may be limited due to the over-riding influence of an ancient hominin adaptation to heat stress in Africa which, even in temperate parts of the continent, continues to the present in terms of generally high summer temperatures. Relatively little variation in mean summer temperatures across the continent (Table 8, page 61) compared to the variation in mean annual and winter temperatures may account for a poor correlation between NSA and mean summer temperature.

Asia

Greater temperature ranges and seasonality in the climatic indices (and also a greater latitudinal range) contribute to stronger correlations for the NSA in Asia compared to Africa (Table 13). Summer temperature again provides the weakest correlation (and is slightly negative), whereas a good correlation with winter temperature is found. The group distributions are plotted against latitude in Figure 23, and show a consistent trend with this climate proxy. Two groups show unusually high NSA for their latitude (although neither could be termed outliers): the Russian Far East (mentioned above), and the Andaman Islands. The latter is a group of special interest here, given the absence of clothing prior to British settlement (discussed in Appendix 2). The high NSA (136.1°, n = 81) presumably reflects morphological adaptation to a quite uniformly warm thermal environment (Table 8, page 63): mean annual and summer temperatures of 27°C, and mean winter temperature 26°C.

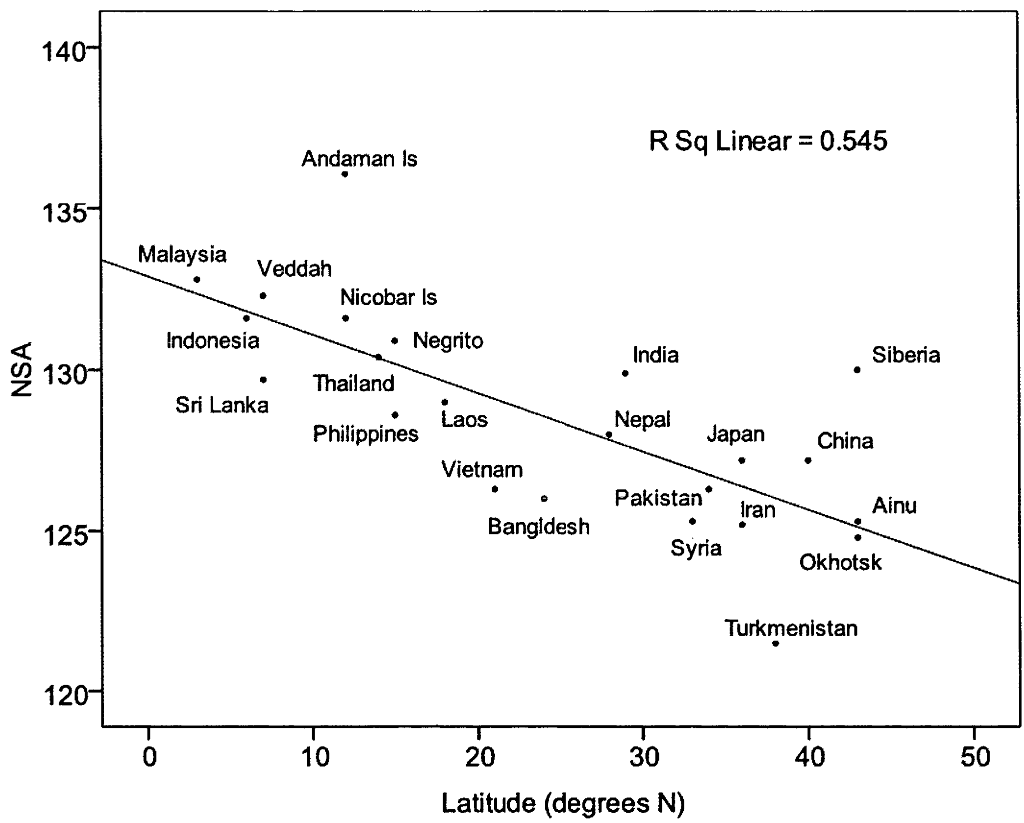
Table 13

NSA and climate correlations for Asia

Climate Variable / Proxy		*n*	*r*	*Significance (* p < .01) (** p < .001)*
L	Latitude (°N/S)	23	-.738	<.001**
A	Annual mean monthly temperature (°C)	23	+.574	.002*
S	Summer (July) mean temperature (°C)	23	-.007	.488
W	Winter (January) mean temperature (°C)	23	+.644	<.001**

Figure 23

Scatterplot of NSA and latitude for Asia



Europe

The NSA correlations for Europe (Table 14) are very low, and they occur in the opposite direction to that anticipated—positive for latitude, negative for temperature. The group distributions are plotted against latitude in Figure 24, which shows Cyprus as an extreme outlier (NSA 118.5°). Given the very small sample size for Cyprus (n = 2) and the anomalous NSA value, the correlations and statistical tests for Europe were repeated with Cyprus omitted (Table 15).

Table 14

NSA and climate correlations for Europe

Climate Variable / Proxy		*N*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	19	+.116	.318
A	Annual mean monthly temperature (°C)	19	-.184	.226
S	Summer (July) mean temperature (°C)	19	-.256	.145
W	Winter (January) mean temperature (°C)	19	-.116	.317

Figure 24

Scatterplot of NSA and latitude for Europe

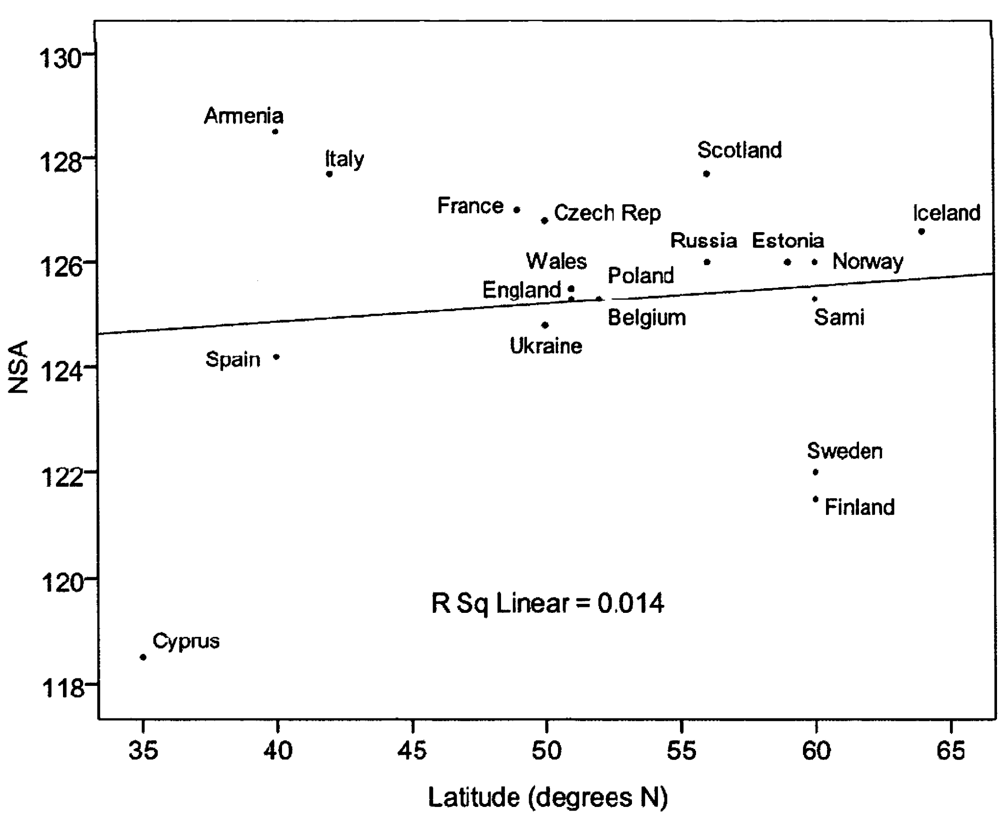


Table 15

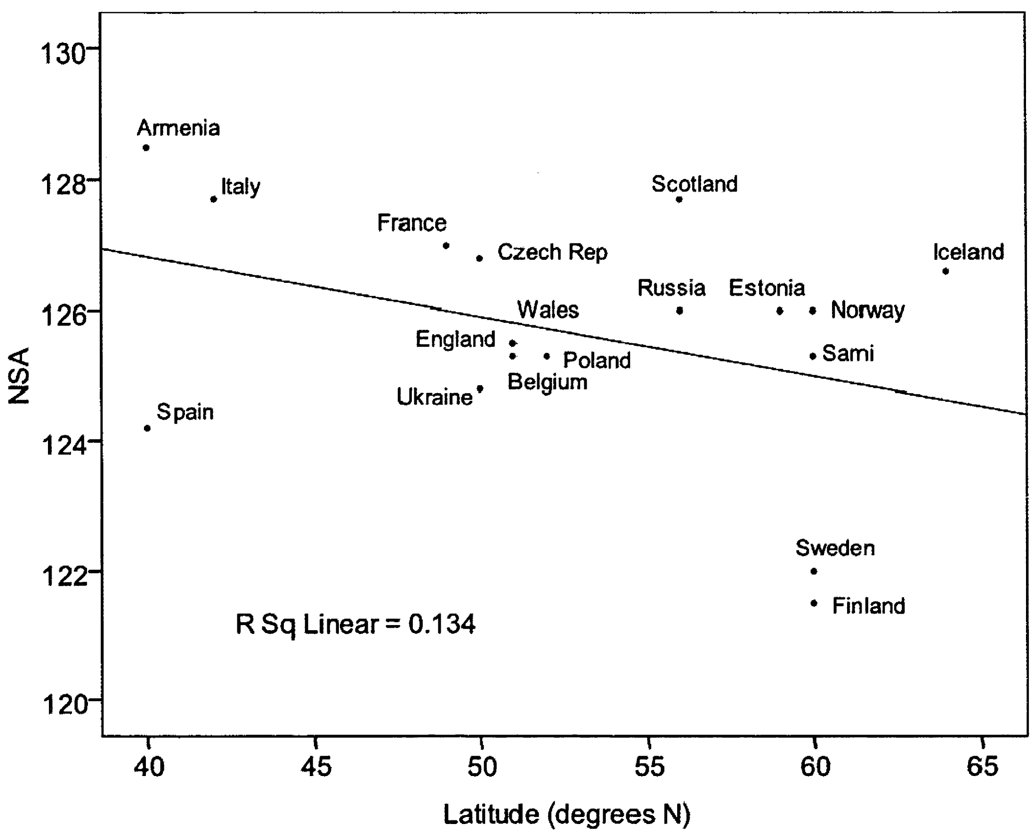
NSA and climate correlations in Europe without the Cyprus sample

Climate Variable / Proxy		*N*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	18	-.366	.067
A	Annual mean monthly temperature (°C)	18	+.364	.069
S	Summer (July) mean temperature (°C)	18	+.228	.182
W	Winter (January) mean temperature (°C)	18	+.297	.116

Without the Cyprus sample, the NSA correlations revert to the anticipated pattern (negative for latitude, positive for temperature), although they remain modest and none reach statistical significance. Assuming that sampling is adequate and that the group means are representative of the respective populations, the question arises as to why climate trends for the NSA in Europe might be relatively minor by other continental standards (Figure 25). One reason may be the comparatively small latitudinal (and hence climatic) range: approximately 25°, compared to ~50° for Asia and ~60° for Africa. Another possible factor affecting any thermal influence on the NSA in Europe may relate to the generally ubiquitous use of thermally-effective (i.e., complex) clothing throughout the continent, which would tend to ameliorate the influence of the external thermal environment.

Figure 25

Scatterplot of NSA and latitude in Europe without the Cyprus sample



North America

The correlation results for North America are shown in Table 16 and the group distributions for latitude are plotted in Figure 26. The correlations are very low and, for mean annual and summer temperatures, occur in the opposite direction to that anticipated on thermal grounds. The number of sample groups (five) for North America is small and, in terms of trends expected on thermal grounds, it is evident that Greenland (NSA 129.3°, $n = 90$) is an anomalous outlier.

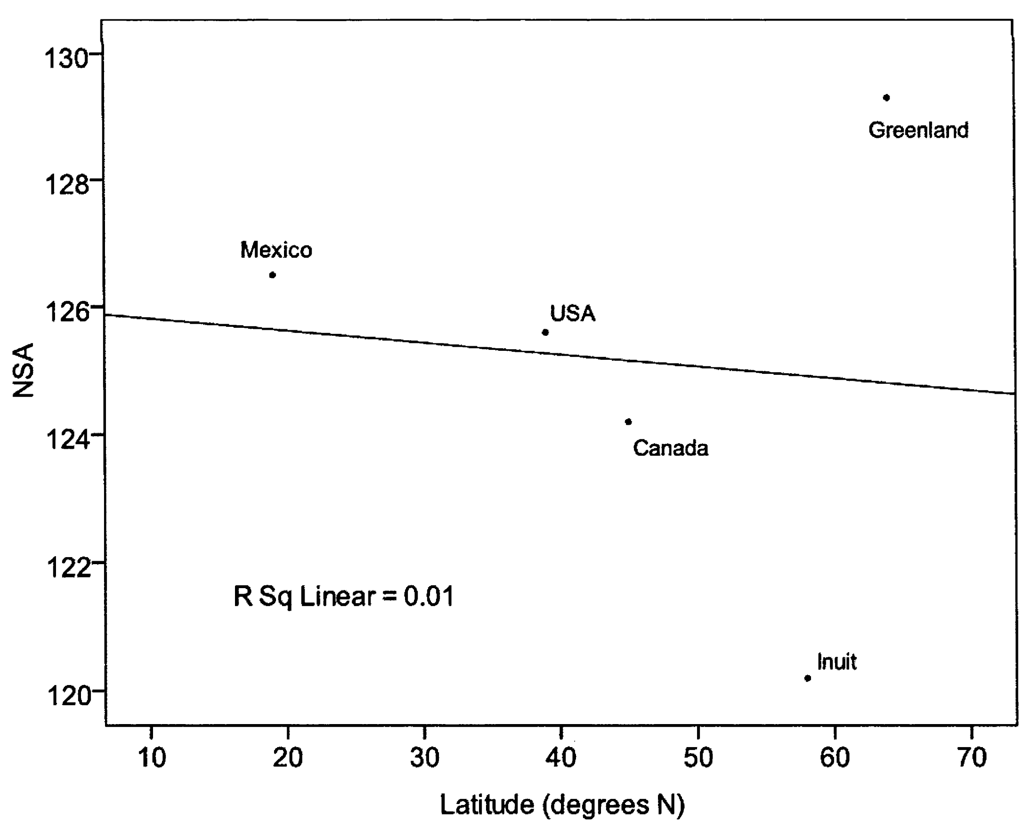
Table 16

NSA and climate correlations for North America

Climate Variable / Proxy		*N*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	5	-.099	.437
A	Annual mean monthly temperature (°C)	5	-.059	.462
S	Summer (July) mean temperature (°C)	5	-.206	.370
W	Winter (January) mean temperature (°C)	5	+.118	.425

Figure 26

Scatterplot of NSA and latitude in North America



Possible reasons for the unexpectedly high NSA for Greenland are not readily apparent: the sample is of adequate size and consists of reasonably well-provenanced collections in three institutions (the SI, MdlH and PM)—all designated as "Eskimos", provenanced mainly to Nuussuaq in western Greenland and Angmagssalik and Nanortalik in the south, respectively. Whether effective "cultural buffering" from the climate could play a role is unclear: the comparable Inuit sample follows the expected climatic trend (although the latter groups, derived from a maritime context on the Aleutian Islands, were probably exposed to greater wind chill stresses). When the analyses are repeated with Greenland omitted (Table 17), the expected climatic trends become evident, although the small number of samples (four) mitigates against the strong correlations reaching statistical significance. The North American group results for latitude (without Greenland) are plotted in Figure 27.

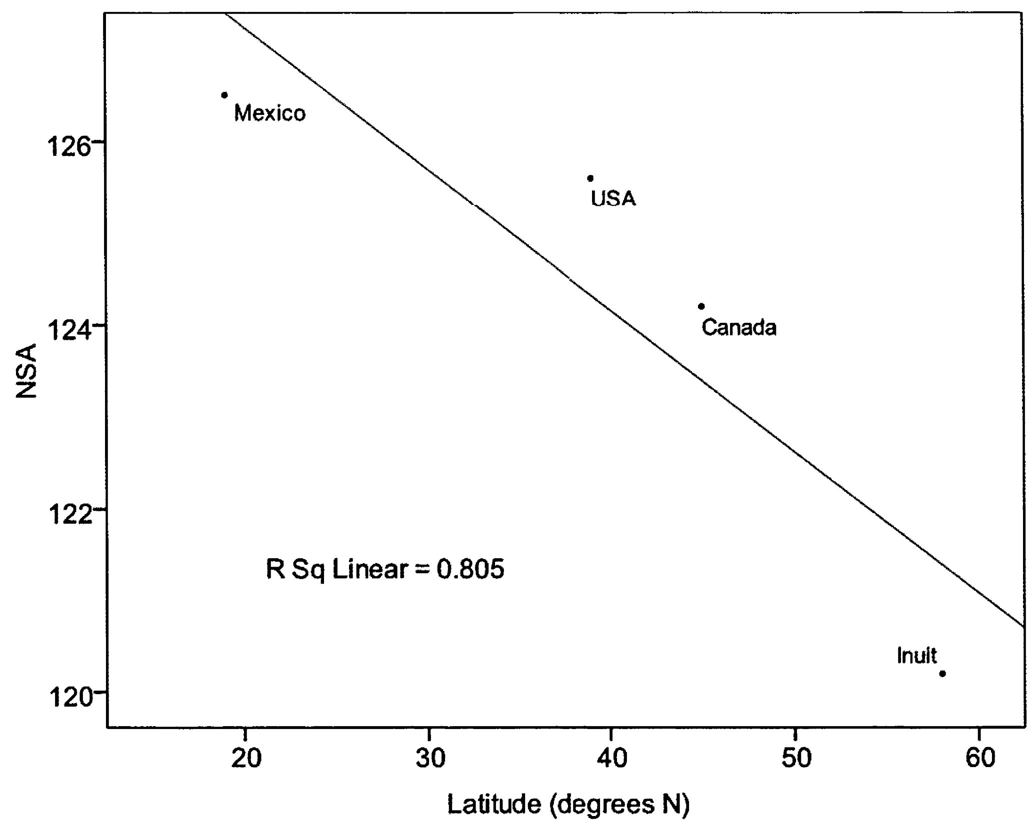
Table 17

North American NSA / climate correlations without Greenland

Climate Variable / Proxy		*N*	*r*	*Significance (* $p < .01$)*
L	Latitude (°N/S)	4	-.897	.051
A	Annual mean monthly temperature (°C)	4	+.847	.076
S	Summer (July) mean temperature (°C)	4	+.696	.152
W	Winter (January) mean temperature (°C)	4	+.596	.202

Figure 27

Scatterplot of NSA and latitude for North America without the Greenland sample



Pacific

Correlation results for the Pacific region are shown in Table 18, and the distribution of group means against latitude is shown in Figure 28. The correlations are modest, and it is evident that one sample—the Moriori (NSA 130.9°, n = 25)—appears to occupy an anomalous position for the high NSA given the latitude (44°S, corresponding to the weather station at Waitangi in the Chatham Islands, the ancestral home of the Moriori off the eastern coast of New Zealand).

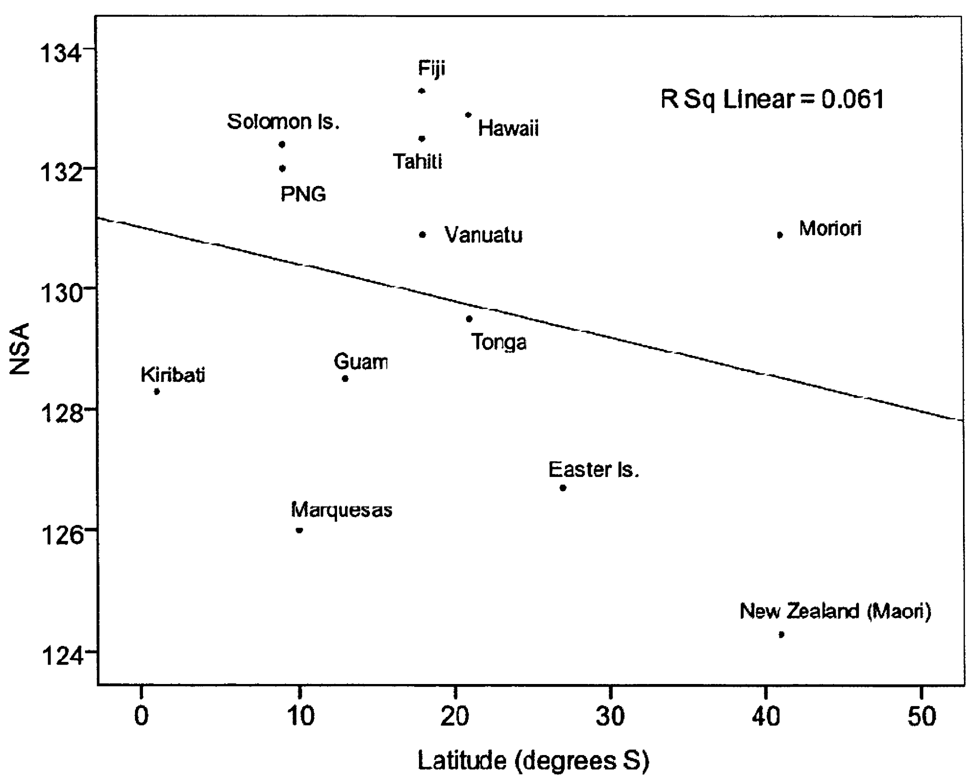
Table 18

NSA and climate correlation results for the Pacific

	Climate Variable / Proxy	*N*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	13	-.248	.207
A	Annual mean monthly temperature (°C)	13	+.357	.116
S	Summer (July) mean temperature (°C)	13	+.368	.108
W	Winter (January) mean temperature (°C)	13	+.346	.123

Figure 28

Scatterplot of NSA and latitude for the Pacific groups



As with the Greenland sample, reasons for the Moriori being an outlier are not readily apparent: while the total sample size is not large ($n = 25$), it derives from four institutions (the AMNH, PM, NHM and LCHES), with the Moriori NSA being high in each of these four collections. The comparable New Zealand sample, the Maori (NSA 124.3°), follows an anticipated thermal trend and, given the cooler and more exposed environment of the Chatham Islands (with slightly lower mean temperatures, as shown in Table 8, page 63), the Moriori might be expected to have a lower, not higher, mean NSA on thermal grounds. Neither is there any likely difference between these two groups in terms of "cultural buffering" from the climate—the Moriori, in fact, may have used less thermally-effective clothing (with no woven garments, in contrast to the Maori) and some historical accounts suggest the males sometimes dispensed with clothing altogether (see chapter 8). Unless the ancestors of the Moriori arrived in the region from a warmer climate more recently than the Maori (for which there is no evidence), their high NSA is unexpected.

Table 19

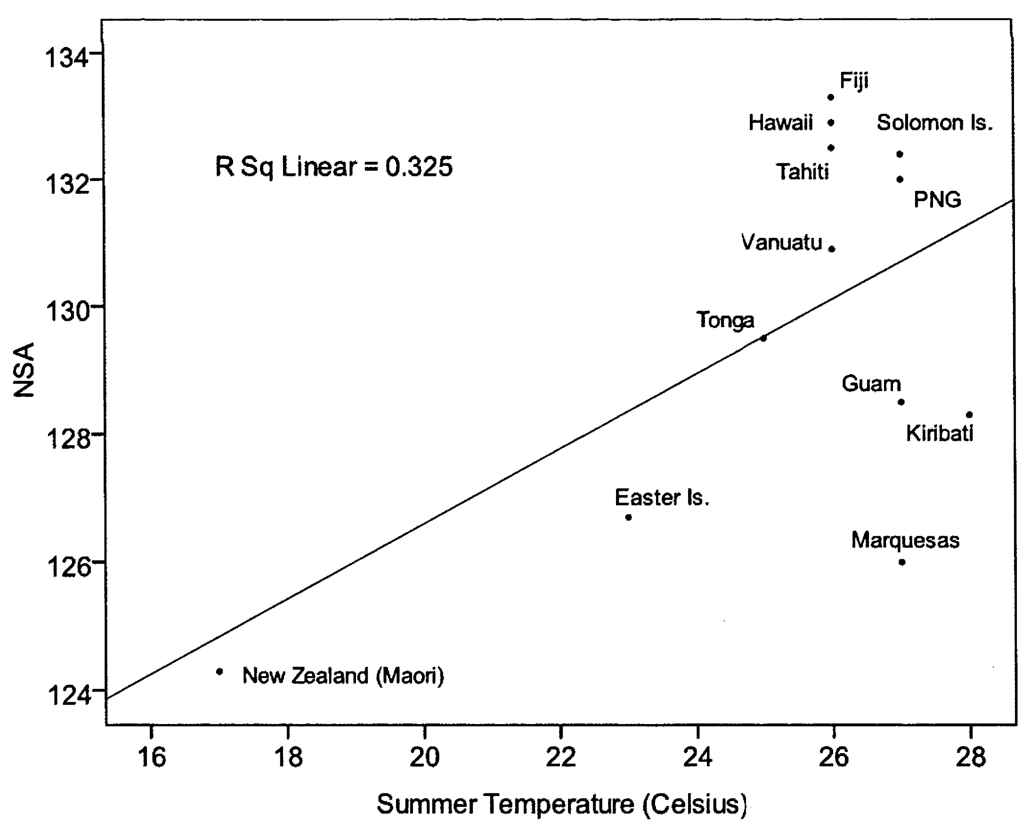
Pacific NSA / climate correlations without Moriori

Climate Variable / Proxy		*N*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	12	-.373	.116
A	Annual mean monthly temperature (°C)	12	+.553	.031
S	Summer (July) mean temperature (°C)	12	+.570	.026
W	Winter (January) mean temperature (°C)	12	+.529	.038

Correlations between NSA and climate for the Pacific omitting the Moriori are shown in Table 19, and the group distributions for summer temperature are plotted in Figure 29. Correlations occur in the expected directions (negative for latitude, positive for temperature), although none quite reach the Bonferroni-corrected (0.01) level. The group means for NSA are distributed in a reasonably logical fashion given the geographical locations, although the Marquesas and the two small Micronesian samples (Kiribati and Guam) have slightly lower NSA means might be expected.

Figure 29

Scatterplot of NSA and summer temperature for the Pacific without the Moriori



South America

Correlation results for South America are given in Table 20, and the group distributions of mean NSA against annual mean temperature are shown in Figure 30. Correlations occur in the expected directions, and while the correlation with latitude is weak, correlations on the temperature variables are modest. None reach statistical significance, although this may be partially attributable to the small number of samples in the analyses (nine groups). The distribution of the groups follows expected thermal trends, however, with the Fuegian sample (mean NSA 122.4°, *n* = 34) falling towards one extreme. A notable outlier is the Bolivian sample (mean NSA 117.6°, *n* = 33) which has the lowest South American NSA here. The sample derives from two collections (at the MdlH and PM), both having low NSA means and with a large proportion (n = 25) provenanced to the Lake Titicaca area at an altitude of 3820m.

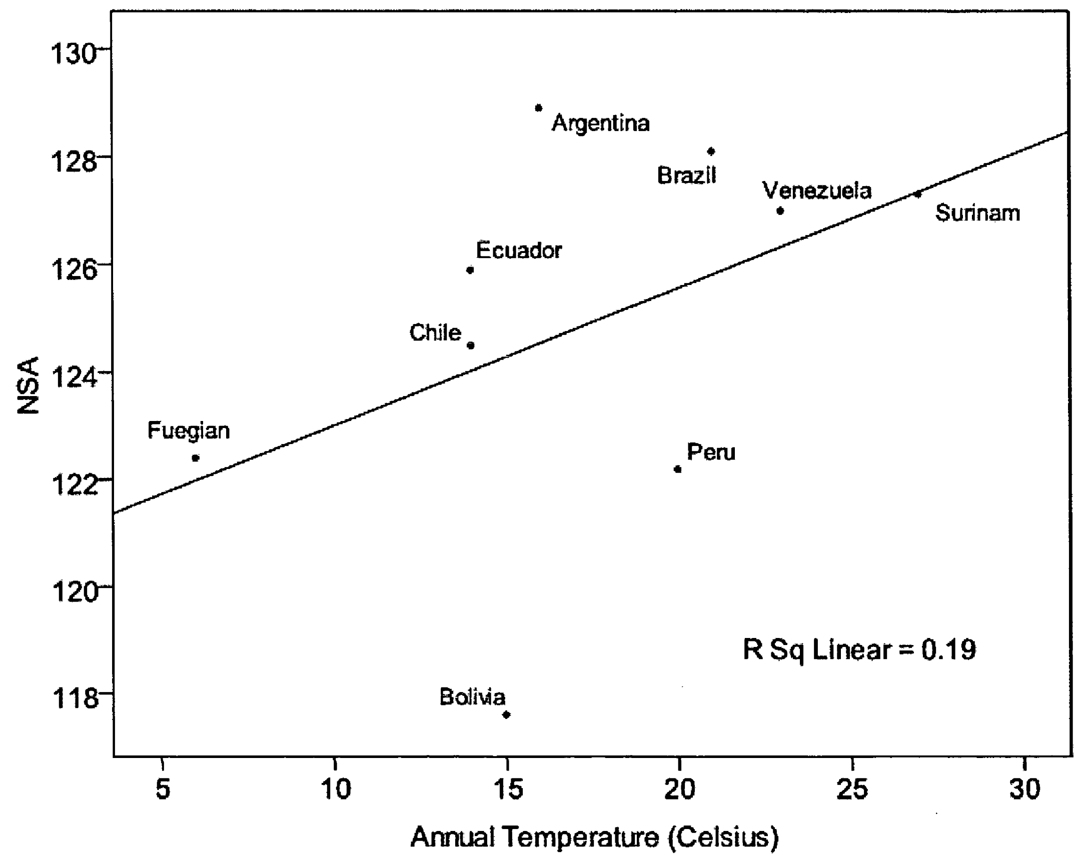
Table 20

NSA / climate correlations for South America

Climate Variable / Proxy		*N*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	9	-.178	.324
A	Annual mean monthly temperature (°C)	9	+.436	.120
S	Summer (July) mean temperature (°C)	9	+.521	.075
W	Winter (January) mean temperature (°C)	9	+.348	.180

Figure 30

Scatterplot of NSA group means for South America



The two Caribbean samples (Dominican Republic and Guadeloupe) were not included in either the North or South American continental analyses given their ambiguous location: most of the region is now linked geo-politically more to North than South America (and so these samples are grouped with North America in the tables), yet the indigenous inhabitants of these two countries (such as the Taínos and the Carib or Kalinago peoples) are linked ethnographically more closely to the northern parts of South America. The Guadeloupe sample is excluded, however, because the four femora are from African black immigrants rather than Native Americans.

Correlation results for South America including the Dominican Republic as the sole Caribbean sample are shown in Table 21; correlations are lower, attributable to a low NSA (relative to a warm climate) for the Dominican Republic (NSA 124.3°, $n = 24$).

Table 21

NSA / climate correlations for South America including Caribbean sample

Climate Variable / Proxy		*N*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	10	-.175	.315
A	Annual mean monthly temperature (°C)	10	+.371	.146
S	Summer (July) mean temperature (°C)	10	+.454	.094
W	Winter (January) mean temperature (°C)	10	+.296	.203

Regional Samples

In addition to the continental analyses, NSA samples from two countries (the U.S.A. and France) can be analyzed more closely in relation to climatic indices as they each comprise a number of discrete samples provenanced to specific areas or localities (12 for the U.S.A., and 18 for France). All the U.S.A. samples are Native American; most derive from the SI, with one each from the AMNH, FLMNH and NHM, while virtually all the French samples derive from the exceptionally well-provenanced collections at the MdlH. Hawaii is excluded from the "continental" U.S.A. analyses, being assigned (as a Polynesian sample) to the Pacific region.

U.S.A.

Descriptive statistics for the U.S.A. samples are given in Table 22. Their locations are shown in Figure 31, and the matched climatic data in Table 23.

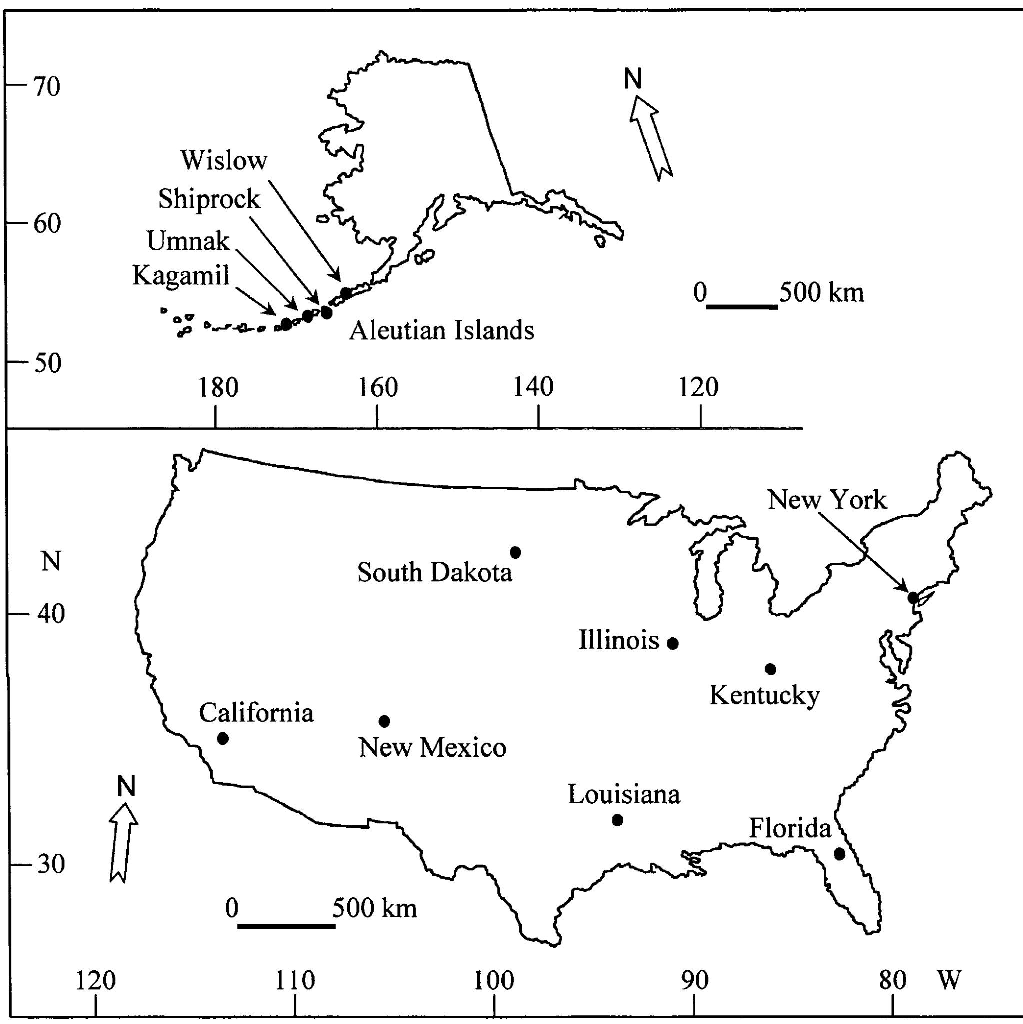
Table 22

Descriptive statistics for the U.S.A. samples

State	*Sample*	*n*	*Mean*	*Minimum*	*Maximum*	*SD*
Alaska	Kagamil Is.	129	120.4	109	131	4.32
Alaska	Shiprock Is.	72	118.3	111	126	3.66
Alaska	Umnak Is.	89	121.9	112	128	3.50
Alaska	Wislow Is.	34	119.2	109	126	3.81
California	Chumash	78	126.4	116	136	3.90
Florida	(various)	306	128.9	110	142	5.06
Illinois	Woodland	100	125.3	116	135	4.16
Kentucky	Archaic	129	123.6	113	132	3.97
Louisiana	Mississippian	118	126.6	116	137	4.50
New Mexico	Hawiku	142	123.4	112	133	4.16
New York	Manhattan Is.	13	125.3	117	137	5.02
South Dakota	Arikara	101	120.2	109	131	4.54

Figure 31

Locations of the 12 samples from the U.S.A.



The U.S.A. samples provide reasonable geographical coverage and, with the inclusion of the Alaskan (Aleutian Islands) samples, extend across a wide range of climatic zones, spanning almost 20°C in terms of mean annual temperatures.

Table 23

Climatic data for the U.S.A. samples

State / Sample	*Institution*	*NSA*	*Weather Station*	*L*	*A*	*S*	*W*
Alaska / Kagamil Is.	Smithsonian	120.4	Nikolski	53	3	9	-1
Alaska / Shiprock Is.	Smithsonian	118.3	Adak Island	52	5	10	0
Alaska / Umnak Is.	Smithsonian	121.9	Nilolski	53	3	9	-1
Alaska / Wislow Is.	Smithsonian	119.2	Dutch Harbor	54	5	11	0
California / Chumash	NHM	126.4	Los Angeles	34	18	22	13
Florida / (various)	FLMNH	128.9	Gainesville	30	20	27	12
Illinois / Woodland	Smithsonian	125.3	Carlinville	39	12	24	-2
Kentucky / Archaic	Smithsonian	123.6	Louisville	38	13	25	0
Louisiana / Mississippian	Smithsonian	126.6	Alexandria	31	19	27	9
New Mexico / Hawiku	Smithsonian	123.4	Albuquerque	35	13	26	1
New York / Manhattan Is.	AMNH	125.3	New York	41	12	25	0
South Dakota / Arikara	Smithsonian	120.2	Pierre	44	8	24	-7

Correlation results are shown in Table 24, and the distributions for mean annual temperature are plotted in Figure 32. All the correlations between NSA and the climatic indices are highly significant and follow the anticipated thermal trends.

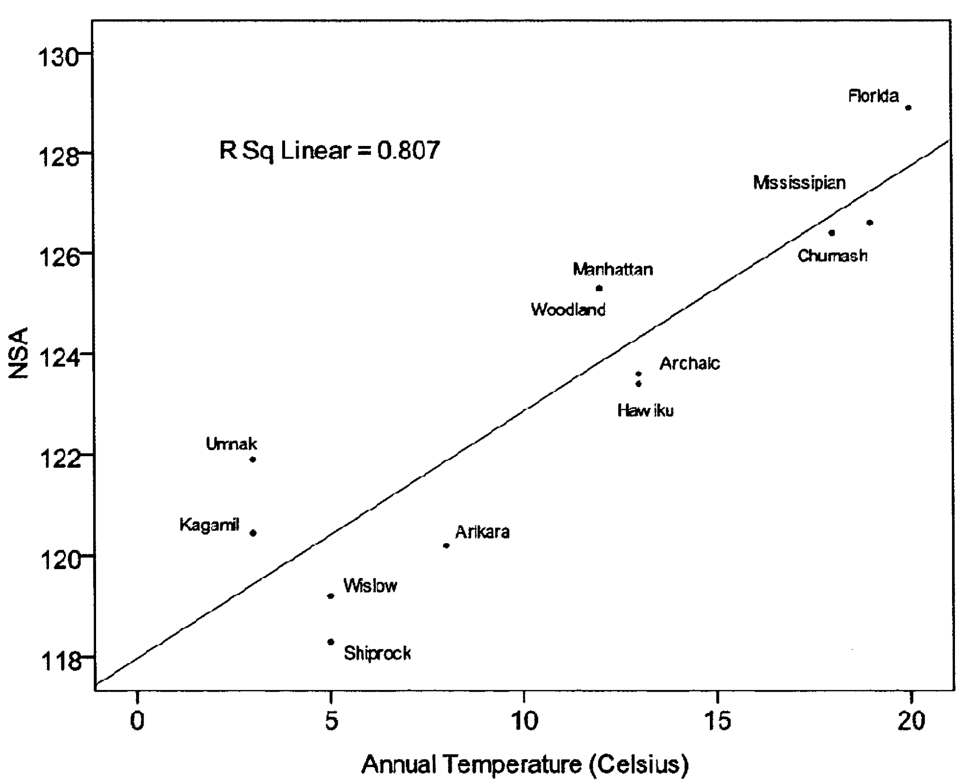
Table 24

NSA / climate correlation results for the U.S.A.

	Climate Variable / Proxy	*n*	*r*	*Significance (* p < .01) (* p < .001)*
L	Latitude (°N/S)	12	-.881	<.001**
A	Annual mean monthly temperature (°C)	12	+.899	<.001**
S	Summer (July) mean temperature (°C)	12	+.751	.002*
W	Winter (January) mean temperature (°C)	12	+.721	.004*

Figure 32

Scatterplot of NSA and annual mean temperature for the U.S.A. groups



France

The locations of the 18 samples from France are shown in Figure 33, and the NSA group means and matching weather stations with associated meteorological data are listed in Table 25.

Figure 33

Map of France showing locations of the 18 regional samples

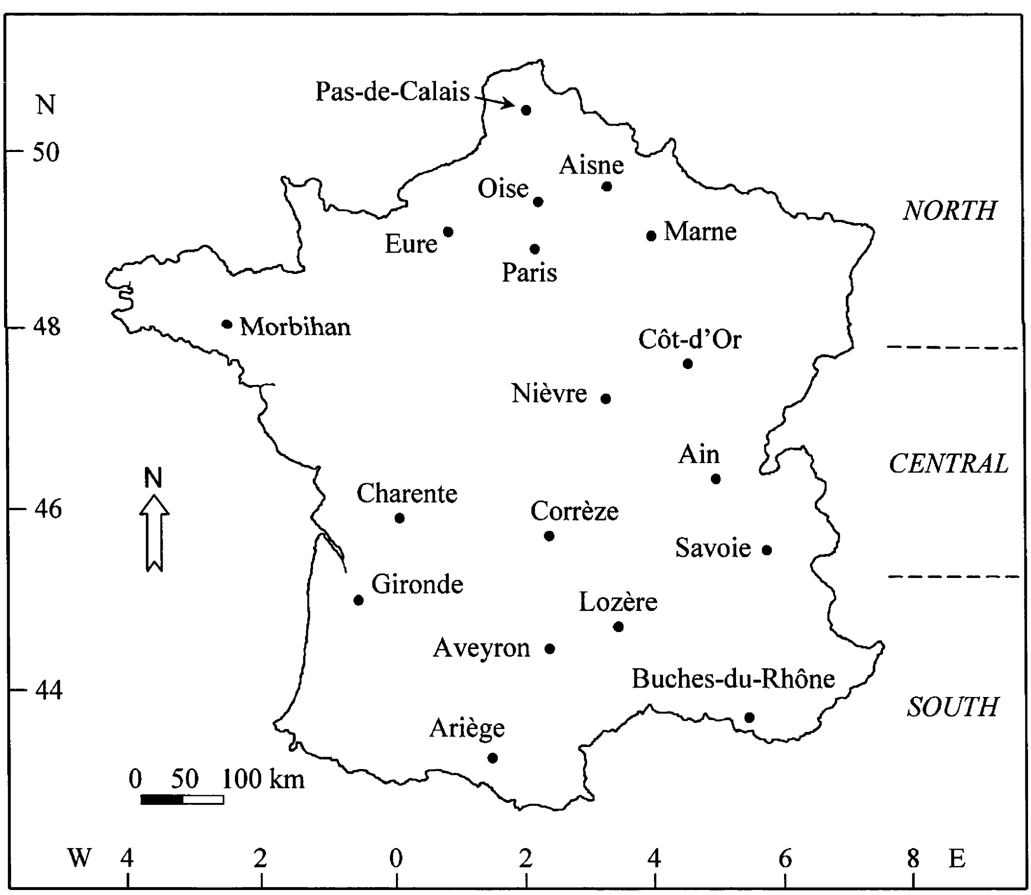


Table 25

NSA means and climatic data for the samples from France

ZONE	*Département*	*Région(s)*	*n*	*NSA*	*Weather Station*	*L*	*A*	*S*	*W*
NORTH	Pas-de-Calais	Nord-Pas-de-Calais	25	126.6	Lille	51	10	17	3
	Aisne	Picardie	8	127.5	Laon	50	9	17	1
	Oise	Picardie	84	126.4	Beauvais	49	9	17	2
	Eure	Haute-Normandie	16	125.6	Rouen	49	10	17	3
	Marne	Champagne-Ardenne	316	126.9	Reims	49	10	18	1
	Paris (Seine)	Île-de-France	102	127.8	Paris	49	11	19	3
	Morbihan	Bretagne	29	124.9	Lorient	48	11	17	6
CENTRAL	Côte-d'Or	Bourgogne	10	128.7	Dijon	47	10	19	2
	Nièvre	Bourgogne	122	127.5	Bourges	47	10	19	3
	Ain	Rhône-Alpes	4	127.0	Lyon	46	11	21	3
	Charente	Poitou-Charentes	7	126.1	Poitiers	47	11	18	3
	Savoie	Rhône-Alpes	4	125.8	Valence	45	12	22	3
	Corrèze/ (Auvergne)	Limousin/ Auvergne	4	123.0	Clermont-Ferrand	46	10	19	1
SOUTH	Gironde	Aquitaine	5	126.4	Bordeaux	45	12	20	6
	Lozère	Languedoc-Roussillon	12	128.7	Millau	44	11	19	3
	Aveyron	Midi-Pyrénées	2	119.5	Toulouse	44	12	21	4
	(Alpes)/ Bouches-du-Rhône	Provence-Alpes-Côte d'Azur	7	127.0	Marseille	43	15	23	6
	Ariège	Midi-Pyrénées	11	128.5	Perpignan	43	15	23	8

Correlation results on NSA and the climate indices for the French samples are given in Table 26, and the group distributions are plotted against winter temperature in Figure 34. The results show essentially no correlation between NSA and the indices. However, most of the NSA means cluster in a small range (~126°-128°) with a couple of outliers, and span only a limited geographical and climatic range (8° of latitude and a 6° difference in mean annual temperatures), compromising the statistical power of the analyses.

3 Zones

One method of exploring these data further is to group the 18 French samples into three zones—north, central and south—which may emphasize any overall trend in the NSA means across the country. Mean NSA values for these three zones and the matched weather stations (with associated climatic data) are given in Table 27.

Table 26

NSA / climate correlations for the samples from France

Climate Variable / Proxy		*n*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	18	+.126	.309
A	Annual mean monthly temperature (°C)	18	+.020	.469
S	Summer (July) mean temperature (°C)	18	-.020	.469
W	Winter (January) mean temperature (°C)	18	+.037	.442

Figure 34

Scatterplot of NSA and winter temperature for the samples from France

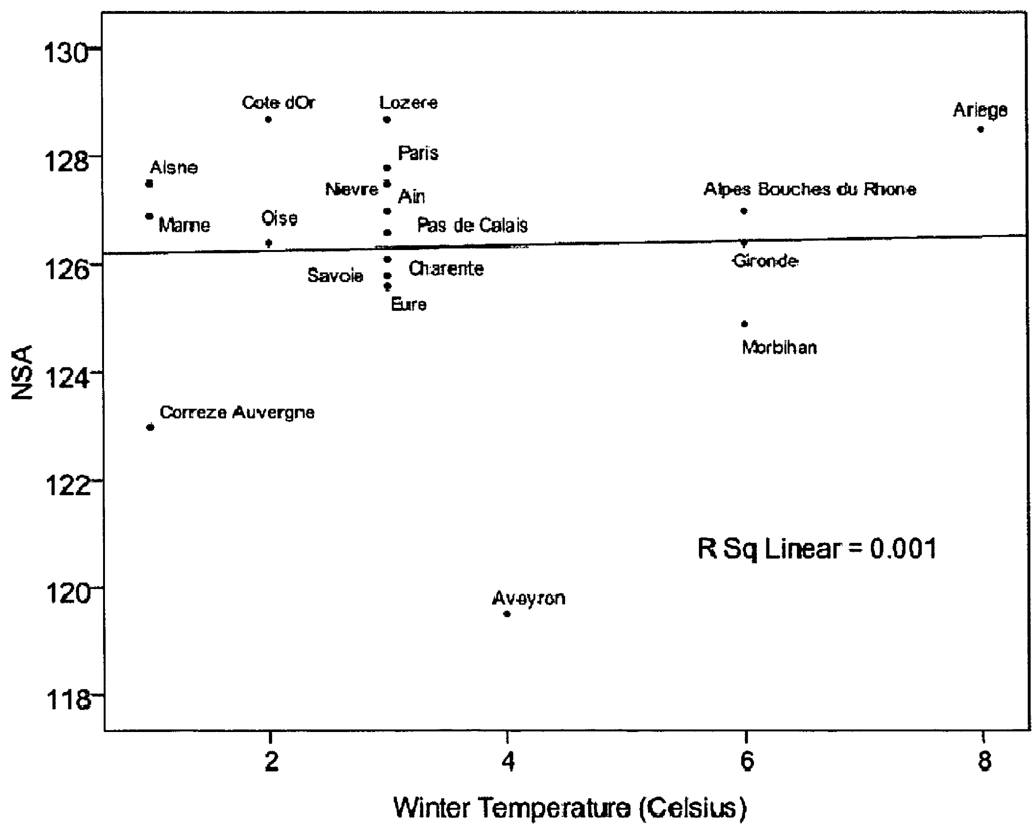


Table 27

Mean NSA and climatic data for the three French zones

ZONE	*n*	*NSA*	*Weather Station*	*L*	*A*	*S*	*W*
NORTH	580	126.9	Reims	49	10	18	1
CENTRAL	151	127.3	Lyon	46	11	21	3
SOUTH	37	127.5	Marseille	43	15	23	6

Correlations between NSA and climatic indices for the French samples grouped into three zones are strong (Table 28), although none reache statistical significance by virtue of the minimal number of groups (three) in the analyses. Despite the small variation in NSA across the total French sample of 768 femora from 18 locations, geographical (and climatic) trends nonetheless emerge at this fine level of resolution when the samples are grouped in a manner that minimizes the impact of outliers and emphasizes any overall patterning in the data (Figure 35).

Table 28

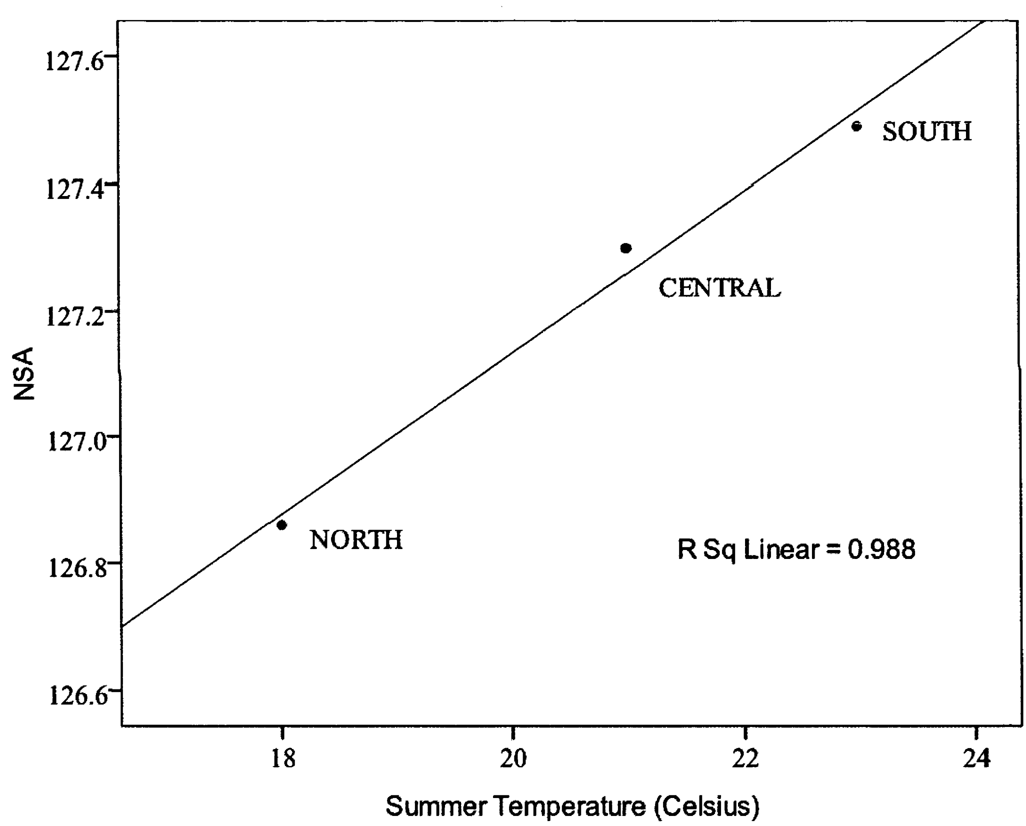
NSA / climate correlations for 3 zones in France

Climate Variable / Proxy		*n*	*r*	*Significance (* $p < .01$)*
L	Latitude (°N/S)	3	-.975	.072
A	Annual mean monthly temperature (°C)	3	+.848	.178
S	Summer (July) mean temperature (°C)	3	+.994	.035*
W	Winter (January) mean temperature (°C)	3	+.943	.108

The small variation (1°) in mean NSA between the three zones spans barely 10° of latitude, with variation in mean annual temperature of 5°C. Yet, with many of the samples deriving from archaeological (mainly neolithic, *c.* 2500 BP) contexts, and the Paris (urban) sample from the early Christian-era Saint-Marcel cemetery, the local populations may have been relatively stable in the respective zones over considerable time scales. The three zones correspond broadly to distinct climatic zones in France which traverse the country from the northeast to the southeast, with the north being predominantly a cool temperate maritime zone, the central zone more continental, and the southern zone influenced by the mild Mediterranean climate.

Figure 35

Scatterplot of summer temperature and mean NSA for three French zones



The Americas Combined

On ethnographic grounds, the two American continental analyses can be combined into a single Native American analysis. The regional U.S.A. samples can also be utilized in this analysis, creating a total of 25 group samples spanning both continents, from the Inuit samples in the north to the Ecuador and Caribbean samples near the equator (excluding the Guadeloupe sample), and with the Fuegians at the southern extreme. Climatic correlations for NSA and results of significance tests for the combined Americas are given in Table 29.

Table 29

NSA / climate correlations for The Americas combined

Climate Variable / Proxy		*n*	*r*	*Significance (* p < .01)*
L	Latitude (°N/S)	25	-.309	.066
A	Annual mean monthly temperature (°C)	25	+.438	.014
S	Summer (July) mean temperature (°C)	25	+.408	.022
W	Winter (January) mean temperature (°C)	25	+.333	.052

In contrast to results for the separate North and South American analyses, and even with the anomalous Greenland sample included, the climatic correlations now approach statistical significance (at the Bonferroni-adjusted .01 level). The distribution of Native American NSA group means on the annual temperature variable is shown in Figure 36; the r^2 value indicates that 19.2% of NSA variance among the Native American groups is "explained" by mean annual temperature variation. With the exception of the Greenland outlier, the group NSA means are distributed in a reasonably predictable fashion based on thermal expectations. Stronger (and statistically significant) climatic correlations emerge when the Americas are analyzed without the Greenland sample (Table 30 and Figure 37).

Figure 36

NSA and annual temperature in The Americas

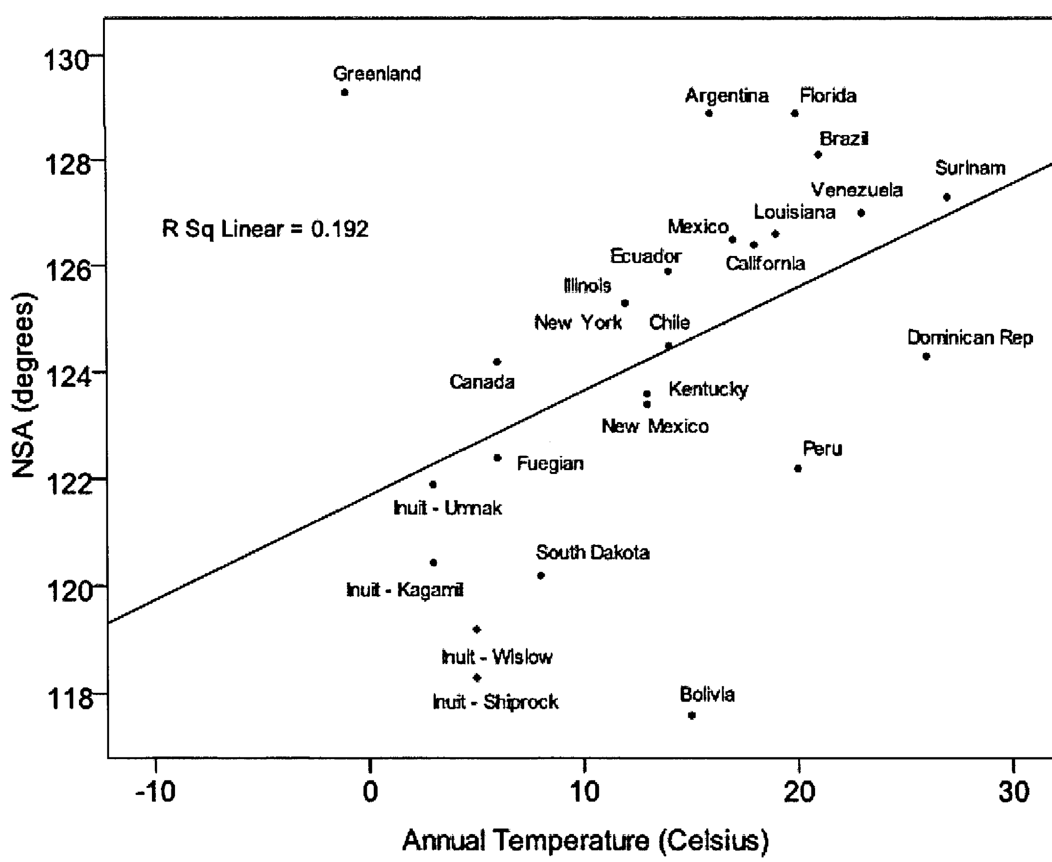


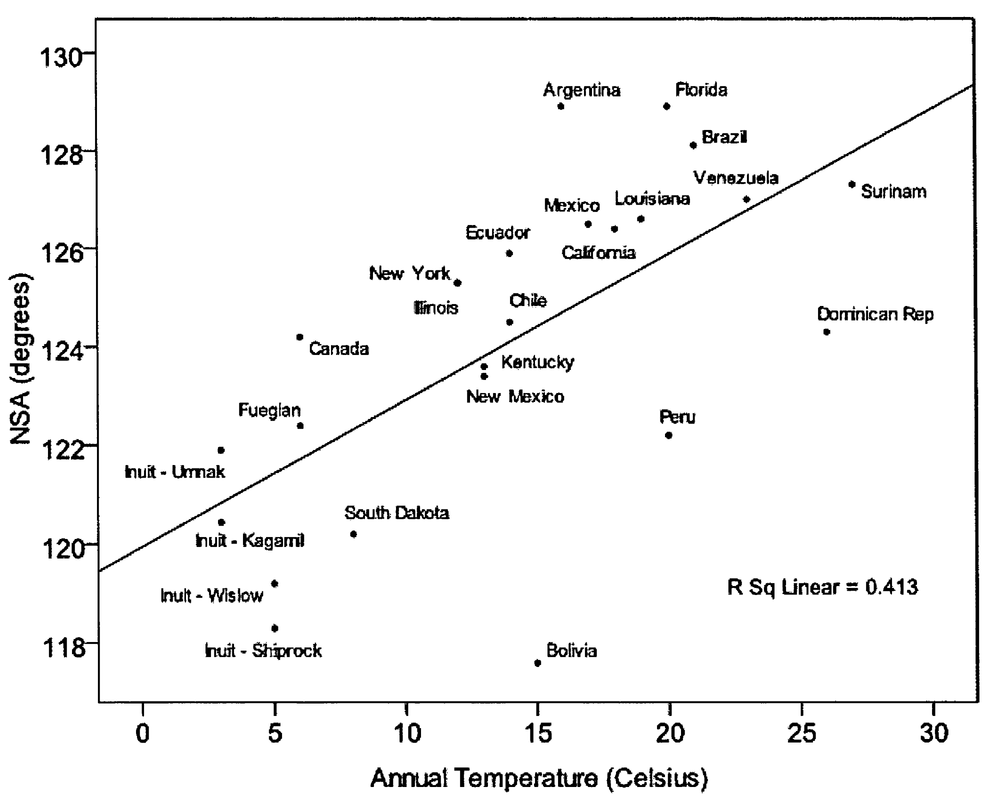
Table 30

NSA / climate correlations for The Americas excluding Greenland

	Climate Variable / Proxy	*n*	*r*	*Significance (* p < .01) (** p < .001)*
L	Latitude (°N/S)	24	-.480	.009*
A	Annual mean monthly temperature (°C)	24	+.643	<.001**
S	Summer (July) mean temperature (°C)	24	+.603	.001*
W	Winter (January) mean temperature (°C)	24	+.473	.010

Figure 37

NSA and annual temperature in The Americas excluding Greenland



Chapter 7: Lifestyle Factors

The extent to which variation in the NSA at the population level is affected by lifestyle as well as climate is examined in this chapter, using fundamental categories relating to economy and mobility. In many cases, this necessarily involves simplification (and, in some instances, over-simplification) of the ethnographic variability and complexity in seemingly straightforward distinctions between a mobile and a sedentary existence, for example, and an agricultural or forager economy. Many of the groups fall into intermediate categories on one or both variables, with a degree seasonal sedentism or with some communities in a given group adopting a more sedentary lifestyle than their mobile neighbors. Forager groups may practise some agricultural activities, and agricultural groups may supplement their diet with forager (e.g., fishing) activities. Nonetheless, for purposes of statistical analysis, classification of cultural groups and subgroups into basic lifestyle categories is required, and a major achievement in this regard is the work of Murdock (1981).

Based on the available information as to provenance, the skeletal collections sampled here have been allocated economic and mobility codes utilizing, to a large extent, the published codes for subsistence economy and settlement pattern in Murdock (1981). In the majority of cases, the country or group samples either cannot be assigned to an individual cultural group, or the assigned Murdock group is a representative example or approximation. The Bantu sample from the NHM, for instance, is provenanced to South Africa and is assigned the Murdock codes for the Tswana, Sotho and Lozi groups which vary somewhat in their degree of sedentism and agricultural activities but are best categorized generally as mobile pastoralists. The Negrito samples from the Philippines (in the MdlH and SI collections) are assigned the Semang code but are provenanced only by geographical location (e.g., "Luzon Island" or "Negrito de Dinalapiphan, Baatan, Philippines").

Economic and Mobility Categories

For samples with mixed classifications (e.g., forager/agricultural, or mobile/sedentary), the predominant category was selected for the analyses (Table 31). The former is designated the "full" code, and the latter the "edit" code. Pastoralist groups are included as agriculturalists in the "edit" code.

Table 31

Economic and mobility categories

Lifestyle category	*Full code*	*Edit code*
Forager	F	F
Forager / agricultural	F/A	F
Agricultural	A	A
Agricultural / forager	A/F	A
Agricultural / pastoralist	A/P	A
Pastoralist / agricultural	P/A	A
Agricultural / urban	A/U	A
Urban	U	U

Urban / agricultural	U/A	U
Mobile	M	M
Mobile / sedentary	M/S	M
Sedentary / mobile	S/M	S
Sedentary	S	S
Uncertain / unknown	O	O

The predominant ("edit") codes are used in the analyses, which exclude groups with small sample sizes ($n < 10$) where the mean NSA may not be a reliable estimate for the population group. The lifestyle and Murdock codes for the 86 groups used in the following analyses are listed in Table 32.

Table 32

Group codes for economy and mobility, and corresponding Murdock codes

Country / group	*n*	Economy		Mobility		Murdock codes
		full	edit	full	edit	(* approximation)
AFRICA						
Algeria (Berber)	28	A/P	A	S/M	M	*C05e (Mozabite)
Angola	11	P	A	S	S	*A04d (Nyaneka)
Benin	10	P/A	A	S	S	*A14a (Fon), A14e (Ewe)
Bushmen	35	F	F	M	M	A02a (!Kung)
Canary Islands	223	P	A	S/M	M	(Berber - Guanches)
Central African Rep.	5	A/P		S		*A21b,c (Baya, Banda)
Chad	10	A	A	S	S	*A22c (Bagirmi), A23a
Congo	6	A		S		*A05d (Kongo)
Egypt	136	U/A	U	S	S	C08b (Phar. Egypt)
Equatorial Guinea	2	A		S		*A12c (Fang)

Ethiopia	5	A		M/S		*C01a, C02a (Amhara)
Gabon	25	A	A	S	S	*A12c (Fang)
Gambia	2	A/P		S/M		*A17a (Fulani)
Ghana	2	A		S		*A15a (Ashanti), A14e
Guinea	2	P/A		M/S		*A17a (Fulani)
Ivory Coast	1	A		S		*A15a, b, A18a (Bambara)
Madagascar	62	A	A	S	S	*A07b (Merina)
Mali	53	A/P	A	S	S	A18a, A19b (Dogon)
Morocco (Berber)	18	A/P	A	S/M	M	*C05e , C07a,b (Kabyle)
Mozambique	10	A	A	S	S	*A06c (Yao)
Niger	43	P/A	A	M/S	M	A19b, A17a (Fulani)
Nigeria	2	A		S		A14c (Yoruba)
Pygmy	16	F	F	S	S	A11a (Mbuti)
Senegal	8	A		S		*A16a (Wolof)
Somalia	47	P	A	M	M	*C01a (Somali)
South Africa						
" Khoikhoi	22	P	A	M	M	A01a (Hottentot)
" Xhosa (Bantu)	10	A/P	A	S/M	M	*A03b,e,f (*e.g.* Tswana)
" Zulu	2	A/P		S		A03c (Zulu)
Sudan (Nubian)	130	U/A	U	S	S	*C03a (Kenuzi)
Tanzania	161	A	A	S	S	*A08a,b,c,d,e (*e.g.* Hehe)
Tunisia (Berber)	2	P/A		M/S		*C07d (Tunisians)
ASIA						
Andaman Islands	81	F	F	M/S	M	E20a (Andamanese)
Bangladesh	2	A		S		E13c (Bengali)
China (Beijing area)	115	U	U	S	S	*E11b (Shantung)
India	47	A	A	S	S	*E13a,c,e (*e.g.*, Punjabi)
Indonesia	11		A		S	
" Borneo	3	A		S		*I04a-d (*e.g.*, Dusun, Iban)
" Java	2	A		S		I03a (Javanese)
" Sumatra	6	A		S		*I02a-d (*e.g.*, Batak)
Iran	6	A/P		S/M		E01a-d (*e.g.*, Hazara)
Japan						
" Ainu	233	F/A	F	S	S	E07a (Ainu)
" Edo period	251	U	U	S	S	E08a (Japanese)
Kampuchea	2	A		S		E23a,b (Khmer, Cambod.)
Laos	2	A		S		*E21b (Li), E21c (Miao)
Malaysia	3	A		S		E25a (Malays)
" Semang	2	F		M		E24a (Semang)
Nepal	2	A/P		S/M		*E12a,c (Lepcha, Sherpa)
Nicobar Is	12	F	F	M/S	M	E17b (Nicobarese)
Okhotsk	19	F	F	M/S	M	*E06a, E06b (Koryak)
Pakistan	4	A		S		*E13c (Punjabi)
Philippines	92	F/A	F	M/S	M	*I01a (Badjau)
" Negrito	37	F	F	M	M	*E24a (Semang)

Siberia	18	P	A	M	M	E05a (Yakut)
Sri Lanka	16	A	A	S	S	E14b (Sinhalese)
Syria	15	A/P	A	S/M	S	C11e,b (Syrians, Druze)
Thailand						
" Bangkok	243	U	U	S	S	E21a (Siamese)
" Chiang Mai	214	U/A	U	S	S	E21a (Siamese)
Turkmenistan	4	P		M		E03a,b (Kazak, Uzbeg)
Veddah	16	F	F	M/S	M	E14a (Vedda)
Vietnam	16	A	A	S	S	E22a (Annamese), *E22b
AUSTRALIA						
South Australia	47	F	F	M	M	*I06a (Aranda)
EUROPE						
Armenia	2	A		S		C25a (Armenians)
Belgium	6	A/U		S		*C18a (Dutch)
Cyprus	2	A		S		*C13a, 12a (Greek, Turks)
Czech Republic	56	A	A	S	S	C21a (Czechs)
England	1707	A	A	S	S	*C17a (New England)
Estonia	4	A		S		*C21b, C24a (Lith., Russ.)
Finland	2	A/P		S		*C19a (Icelanders)
France						
" mesolithic	24	F	F	S	S	*C16a (Fr. Canadians)
" neolithic	393	A	A	S	S	*C16a (Fr. Canadians)
" provincial	249	A/U	U	S	S	*C16a (Fr. Canadians)
" urban (Paris)	102	U	U	S	S	*C16a (Fr. Canadians)
Iceland	146	A/P	A	S	S	C19a (Icelanders)
Italy	10	A	A	S	S	C14b (Neopolitans)
Norway	4	A/P		S		*C19a (Icelanders)
Poland	8	U		S		*C23b (Hungarians)
Russia						
" neolithic	30	A	A	S	S	C24a (Russians)
" urban (Moscow)	16	U	U	S	S	C24a (Russians)
Sami	12	P	A	M	M	C20a (Lapps)
Scotland						
" Orkney Islands	83	A	A	S	S	*C17a, b (N. Eng., Irish)
" Shetland Islands	351	P/A	A	S	S	*C17a, b (N. Eng., Irish)
Spain						
" Balearic Islands	12	A	A	S	S	C15b (Spaniards)
" Basque	2	A/P		S		C15a (Basques)
Sweden	2	A		S		*C19a (Icelanders)
Ukraine	10	U	U	S	S	C24b (Ukrainians)
Wales	2	A/P		S		*C17a (New England)
NORTH AMERICA						
Canada						

" British Columbia	265	F	F	S/M	M	N06a-e (*e.g.*, Haida)
" Ontario	5	F		M		N18e (Chippewa), N19d
" St Lawrence	2	A		S		N19a,b (Iroquois, Huron)
Dominican Republic	24	A	A	S	S	S04b (Taino), S05a
Greenland	90	F	F	M	M	N02c, N02e (Eskimo)
Guadeloupe	4	A		S		S04b, S05a (Callinago),b
Inuit (Aleutian Is.)	324	F	F	S	S	N01a (Aleut)
Mexico						
" Chihuahua	11	A	A	S	S	N24b (Tarahumara)
" Coahuila	16	F/A	F	M	M	*N21d (Western Apache)
" Valley of Mex.	38	A/U	U	S	S	*N24a (Aztec) -e, N25a-c
U.S.A.						
" Chumash	78	F	F	S	S	*N09c (Coast Yuki)
" Florida	306	A/F	F	S	S	N20a,b d (*e.g.*, Choctaw)
" Illinois	100	A/F	F	S	S	N16e, N18a-c, N19a
" Kentucky	129	F	F	M	M	*N18b, N19c, N20e
" Louisiana	118	A	A	S	S	N20b, N20c (Natchez)
" New Mexico	142	A	A	S	S	N22a (Zuni), N22c (Tewa)
" New York	13	A/F	F	S/M	M	N19d (Delaware)
" South Dakota	101	A/F	F	S/M	M	N17d (Arikara)
PACIFIC						
Easter Island	94	A	A	S	S	I17e (Easter Island)
Fiji	4	A		S		I15a (Lau)
Guam	2	A/F		S		I22c (Chamorro)
Hawaii	12	A	A	S	S	I18b (Hawaiians)
Kiribati	4	A/F		S		I20a (Makin)
Marquesas Islands	2	A/F		S		I17a (Marquesans)
New Zealand						
" Maori	20	A/F	A	S	S	I18a (Maori)
" Moriori	25	F	F	S	S	*I18a (Maori)
PNG						
" West Papua	18	A/F	F	S	S	*I09a-e (*e.g.*, Keraki)
" New Britain	31	A/F	A	S	S	I12c (Lakalai)
" unspecified	10	A/F	A	S	S	*I08a-f, I09a-e, I10a-e
Solomon Islands	20	A/F	A	S	S	I13a-d (*e.g.*, Buka, Kaoka)
Tahiti	11	A	A	S	S	I17b (Tahitians)
Tonga	4	A		S		I16c (Tongans)
Vanuatu	76	A	A	S	S	I14a,b,d (*e.g.*, Ajie, Lifu)
SOUTH AMERICA						
Argentina	108	A/P	A	S/M	M	S23a (Mapuche)
Bolivia	33	A/P	A	S	S	S13b (Aymara)
Brazil	9	F/A		M/S		*S16a-e (*e.g.*, Shavante)
Chile	49	A/P	A	S/M	M	S23a (Mapuche)
Ecuador	193	F/A	F	S/M	M	*S11a (Tucano), S15a

Peru						
" Anton site	105	A/U	A	S	S	*S13a (Wari empire)
" Chicama	106	A	A	S	S	*S13a (Inca), S13b
Surinam	4	A/F		S		*S12b (Campa)
Venezuela	68	U	U	S	S	*S09a (Carib), S12b
Tierra del Fuego						
" Fuegian	18	F	F	M	M	S24b, S25a,b (Alacaluf)
" Ona	2	F		M		S24b (Ona)
" Yahgan	14	F	F	M	M	S25a (Yahgan)

Economy and NSA

Descriptive statistics for the NSA in the three economic categories are given in Table 33, and the NSA values for these economic categories are plotted in Figure 38.

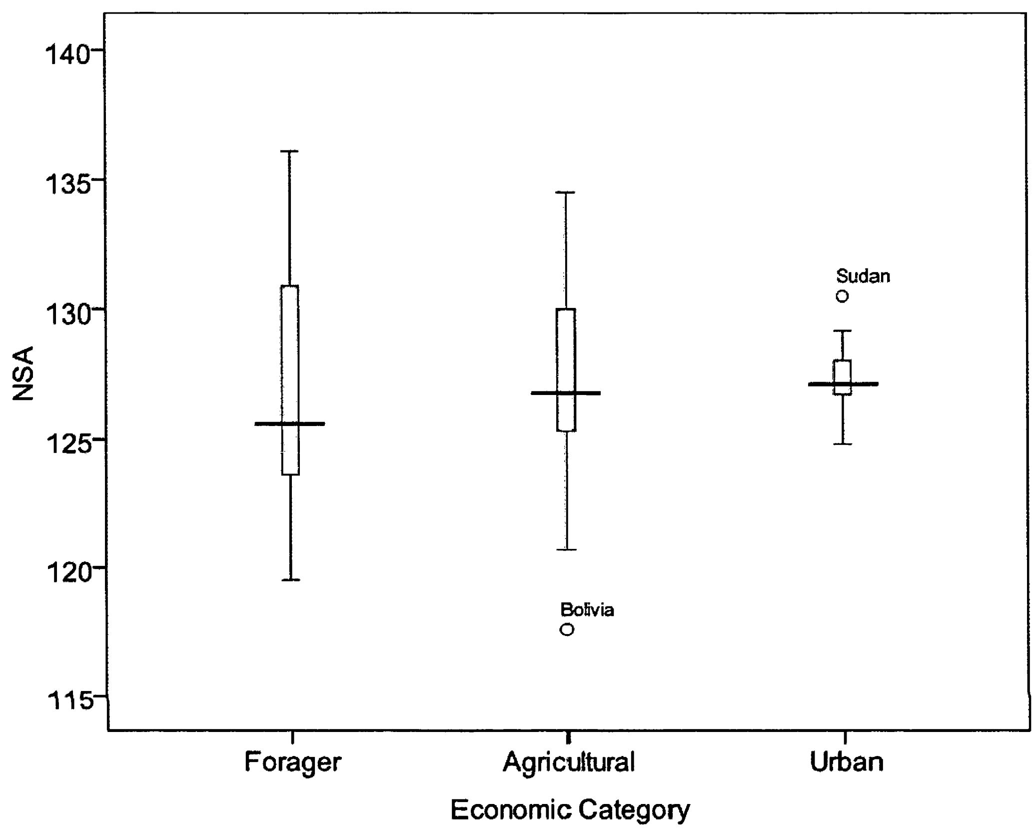
Table 33

Descriptive statistics for the NSA among the three economic categories

Economic Category	*n*	*Mean*	*Minimum*	*Maximum*	*SD*
Forager	26	126.5	119.5	136.1	4.37
Agricultural	48	127.3	117.6	134.5	3.60
Urban	12	127.8	124.8	131.6	1.84

Figure 38

Distributions of the NSA in the three economic categories



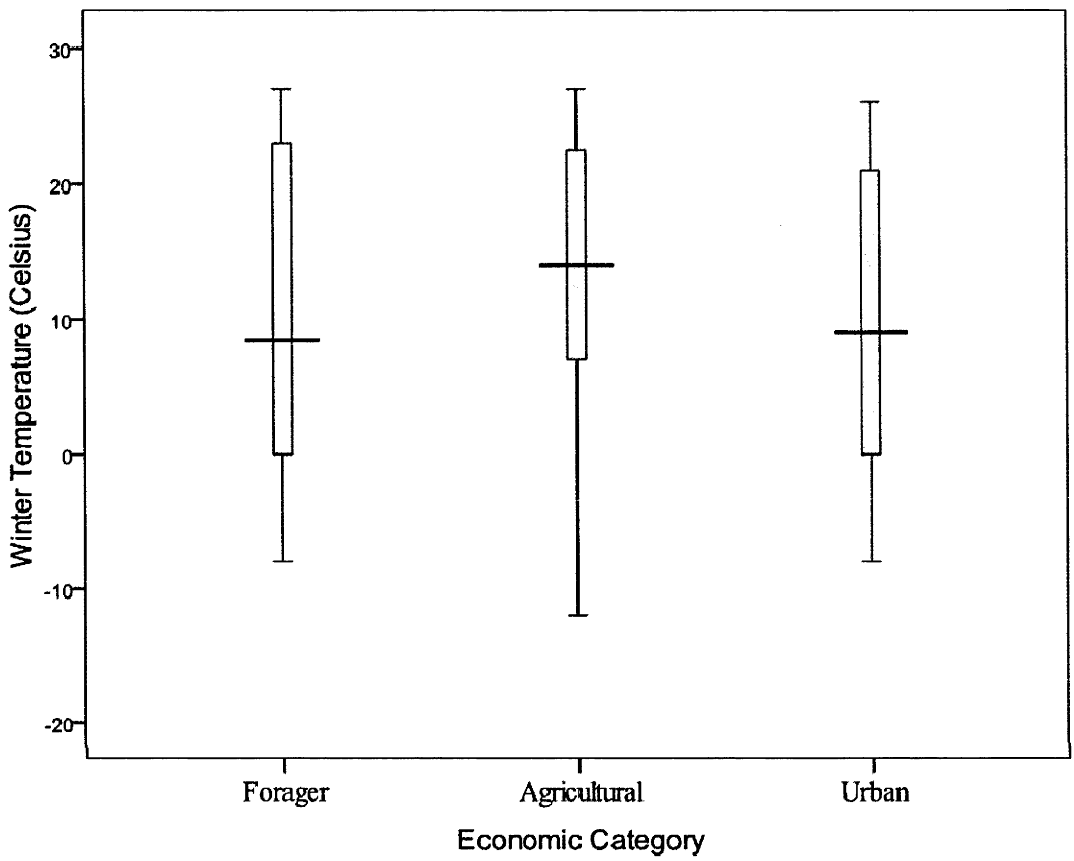
The NSA shows two trends across the economic categories: the first is a steady reduction in the range of the NSA values moving from forager to agricultural and urban groups, and the second is a small increase in the mean NSA moving also from forager to agricultural and urban groups. The first trend, a narrowing of the range in NSA, is difficult to explain in terms of any changes in biomechanical stresses due to altered activity levels, but is more explicable in terms of reduced exposure to the external thermal environment associated with these economic transitions. The agricultural and especially the urban lifestyles entail greater cultural buffering from climate compared to a forager existence, in relation to both the built environment (e.g., the thermal effectiveness of shelter) and also, typically, the use of clothing. This same factor, cultural buffering from the climate, can also account for the increase in NSA across the economic categories: it results in an effectively warmer microclimate for the human body, which may be expected to lead to an increase in the NSA on thermal grounds.

Economy and Climate

The role of insulation from climatic influences on the NSA is illustrated by the similar ranges in environmental temperatures to which groups in these three economic categories are exposed (Figure 39). The three categories are seen to straddle comparable ranges of climatic variation, yet the NSA demonstrates markedly reduced variation due to increased cultural buffering associated with the transition to the agricultural and urban lifestyles.

Figure 39

Distributions of winter temperatures for the three economic categories

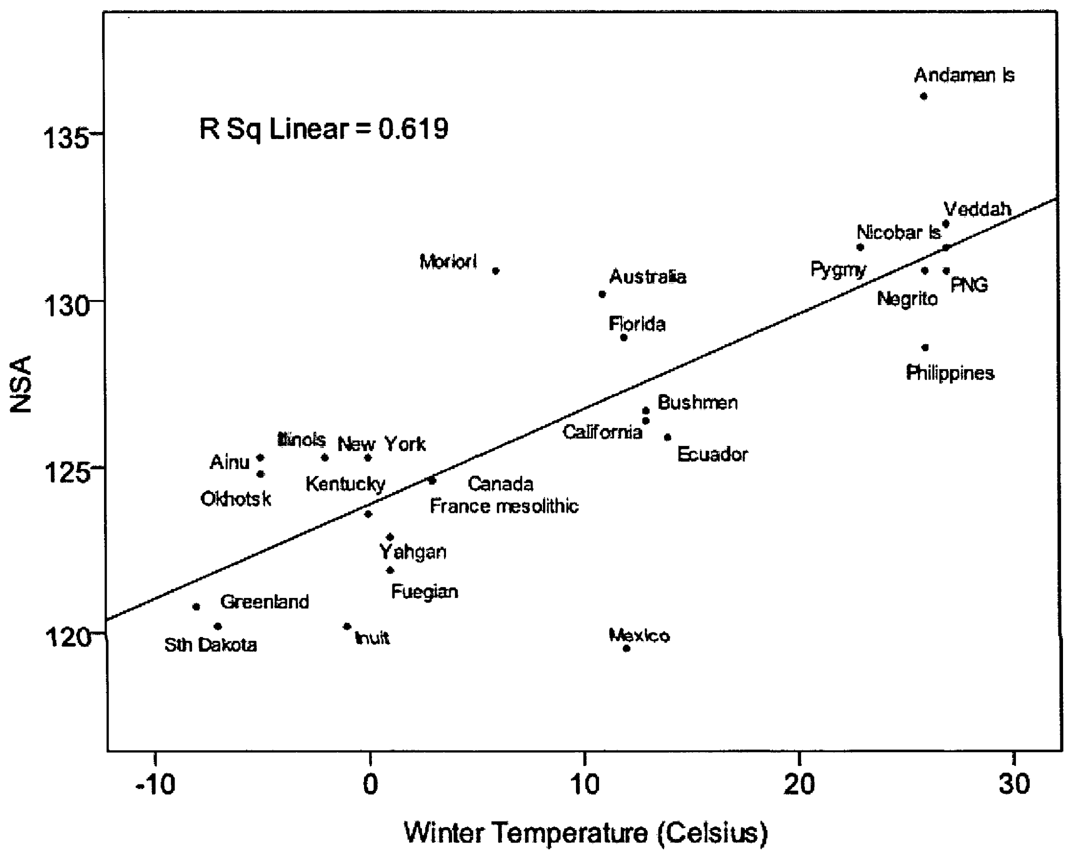


Foragers and Climate

Within the forager groups (n = 26), the NSA shows consistent sensitivity to environmental variation (Figure 40), with a strong correlation (r = +.787) between the NSA and mean winter temperature.

Figure 40

NSA and winter temperature for the forager groups

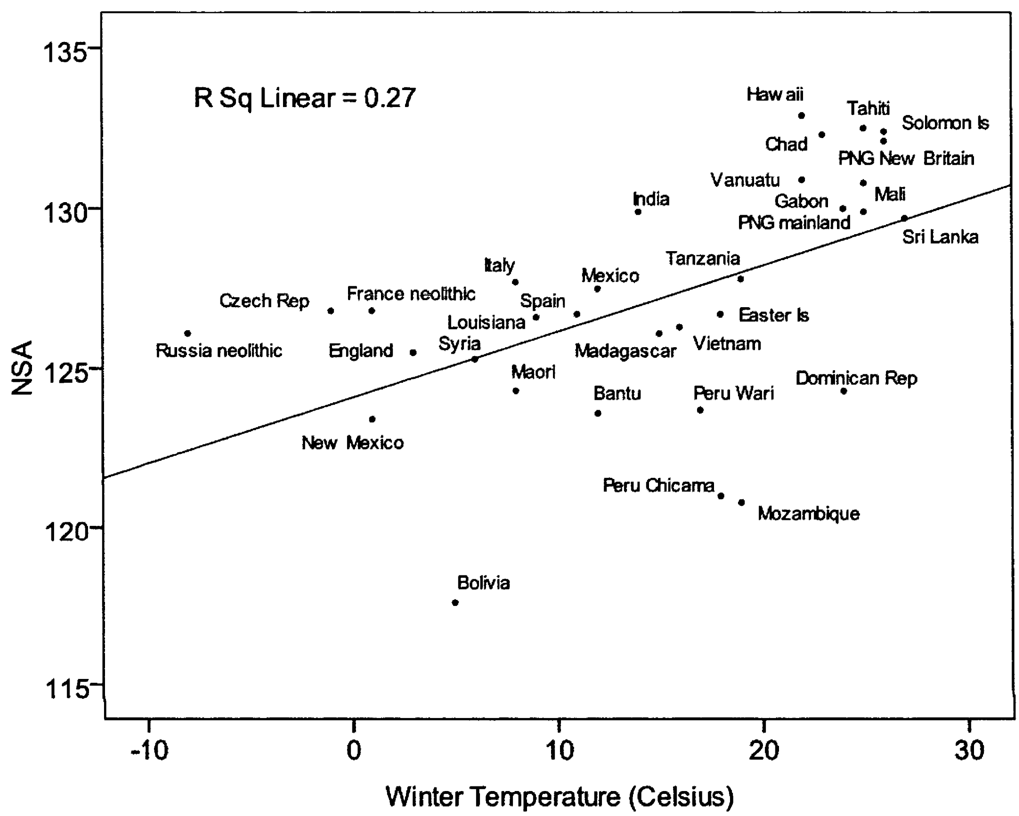


Agriculturalists and Climate

The NSA maintains its variation in relation to climate among the agricultural groups (n = 46), seen for instance with winter temperature (Figure 41, r = +.437), but the sensitivity to climate is diminished compared to the forager groups.

Figure 41

NSA and winter temperature for the agricultural groups

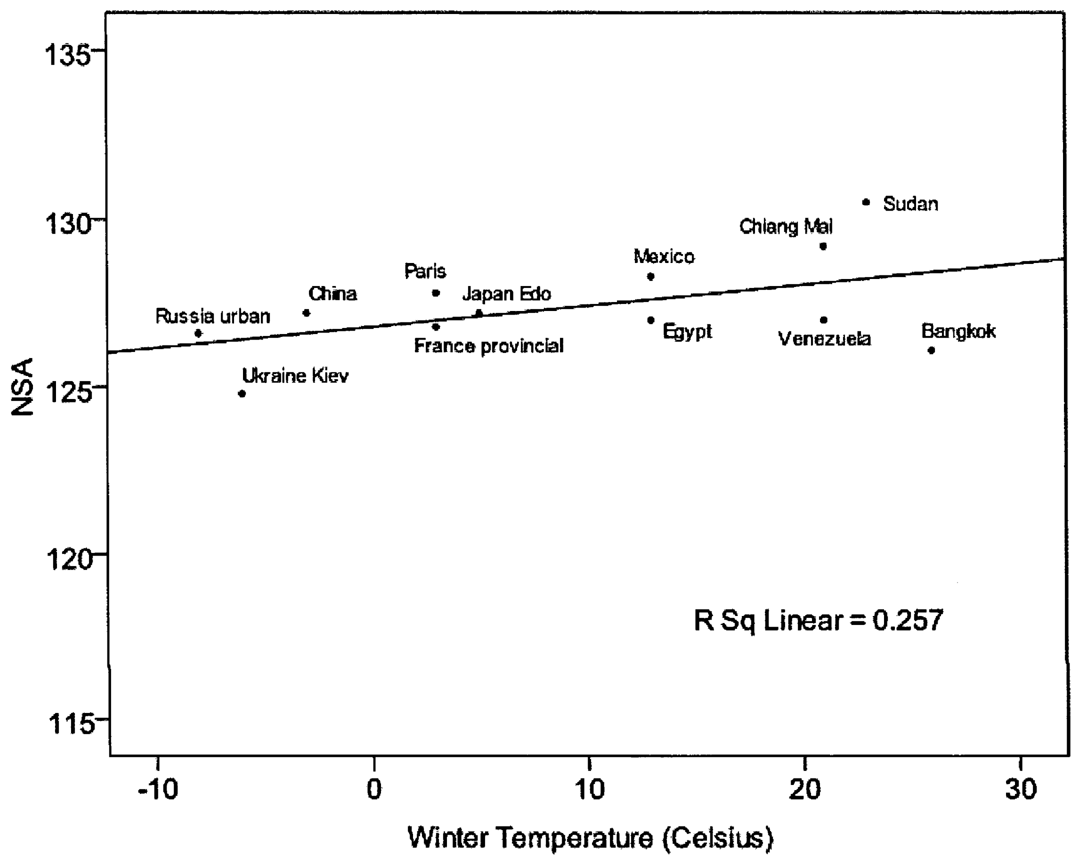


Urban Groups and Climate

Similarly, the correlation between NSA and climate is maintained in the urban groups (n = 12), seen again with winter temperature (Figure 42, r = +.787), but the range of variation is markedly reduced compared to agricultural and especially forager groups, attributable to greater cultural buffering from the environment.

Figure 42

NSA and winter temperature for the urban groups



Mobility and NSA

Descriptive statistics for the NSA among the mobile (n = 29) and sedentary (n = 57) groups are listed in Table 34, and the distributions of NSA among the two categories are plotted in Figure 43.

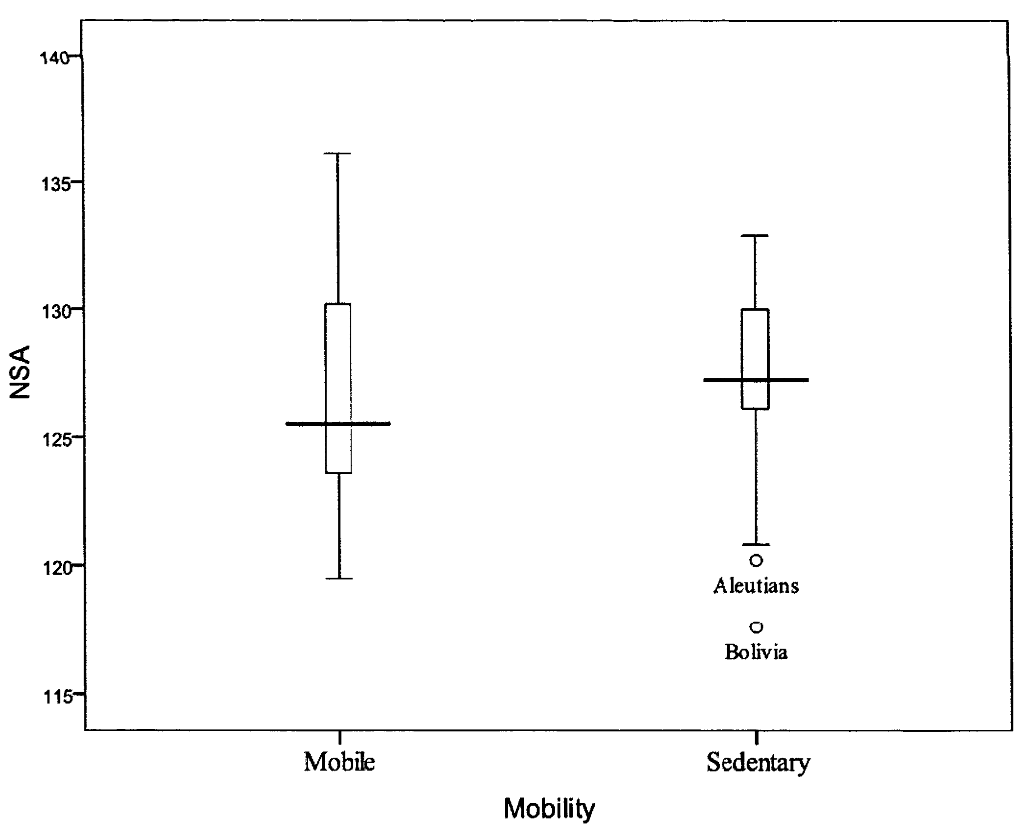
Table 34

Descriptive statistics for NSA in the two mobility categories

Mobility Category	*n*	*Mean*	*Minimum*	*Maximum*	*SD*
Mobile	29	126.4	119.5	136.1	4.29
Sedentary	57	127.5	117.6	132.9	3.27

Figure 43

Distributions of the NSA in the two mobility categories



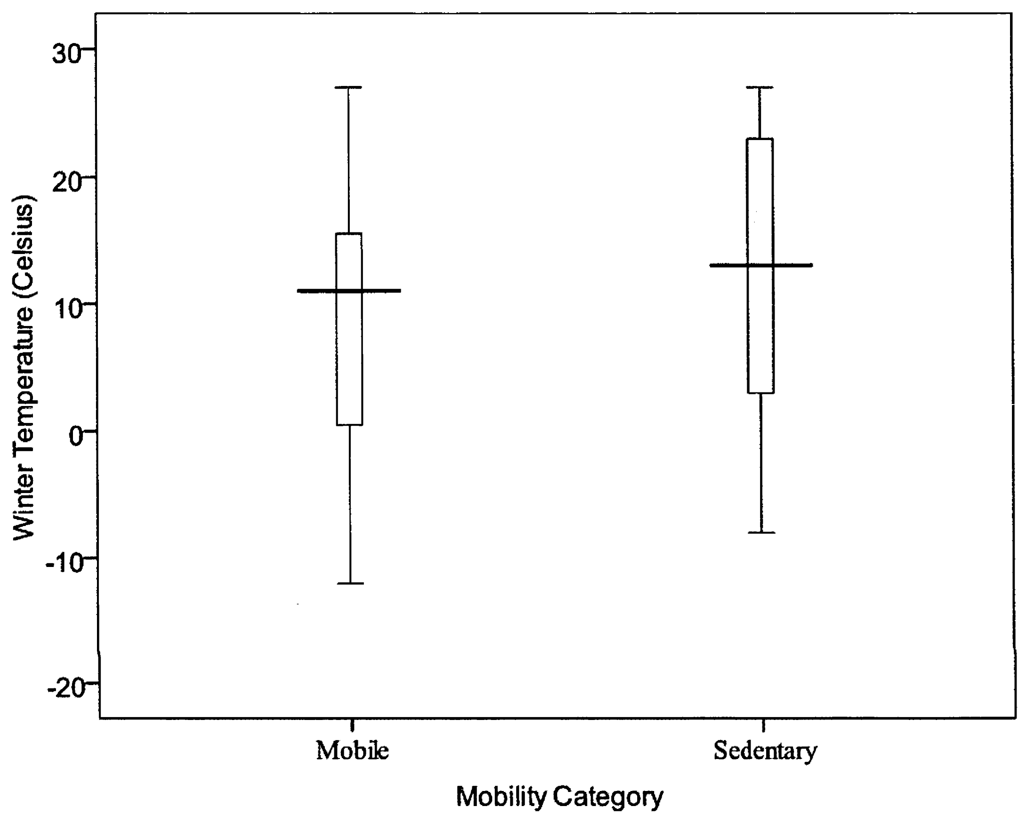
Compared to mobile groups, the NSA is both somewhat higher and more restricted in range among the sedentary groups (with this reduced angle occurring despite a significantly larger sample size). Whilst a higher angle might be interpreted as reflecting a less physically-demanding lifestyle among sedentary as opposed to mobile populations, the reverse could be equally be argued. However, greater insulation from climatic variation among sedentary groups can account for both trends. In Figure 43, the two outliers (Aleutians and the Bolivian sample) are also readily explicable on thermal grounds: the low NSA on the Aleutian Islands reflecting cold stress in a high latitude environment and, in the case of Bolivia, cold stress in a high altitude environment.

Mobility and Climate

The two mobility categories span similar ranges of environmental temperature (Figure 44), and hence the reduced range in NSA among sedentary groups cannot be explained by a reduced climatic range. Indeed, the bulk of sedentary groups are spread across a wider, not narrower, band of winter temperatures, so a greater NSA range would be expected were it not for the effects of greater cultural buffering. The sedentary groups in this study occupy milder climates in terms of mean winter temperatures, which might in itself contribute to the higher NSA in sedentary groups. Another factor may the sampling differences: some 40% of the sedentary groups occur in Africa and the Pacific (compared to 30% for the mobile groups).

Figure 44

Distributions of winter temperatures for the two mobility categories

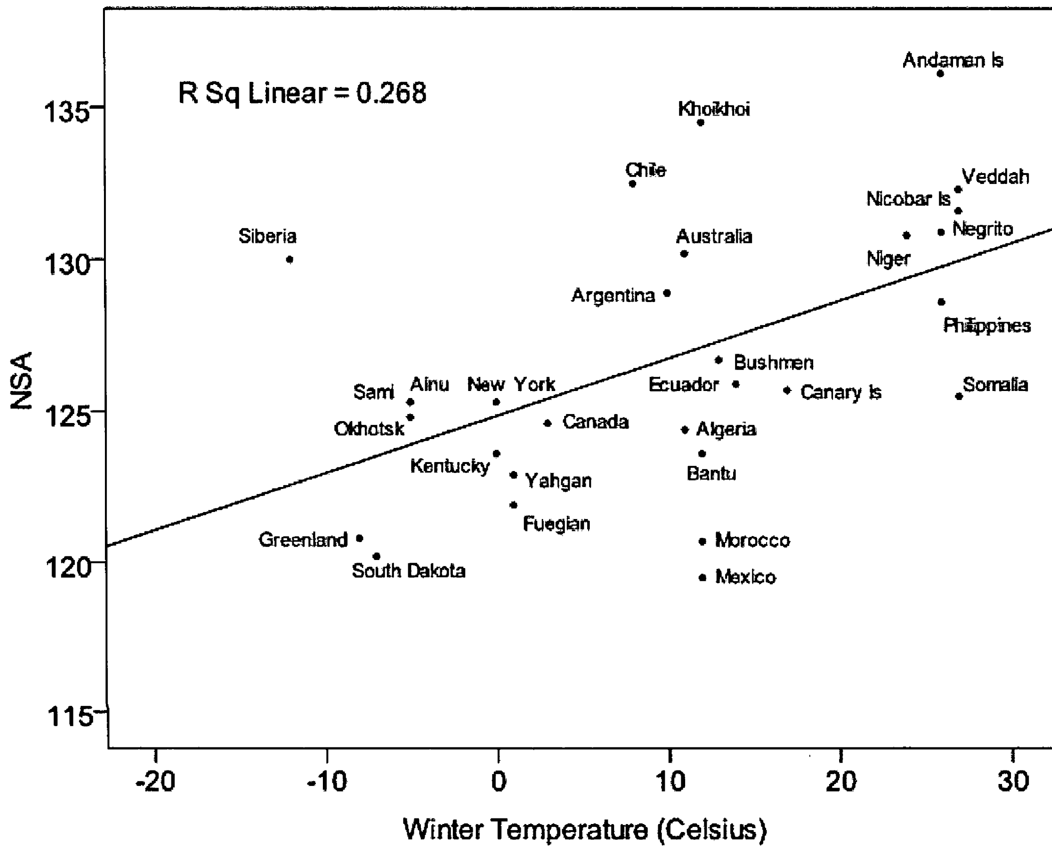


Mobile Groups and Climate

The NSA among mobile groups follows the predicted thermal trend (Figure 45) with, for instance, a Pearson correlation of +.518 between NSA and mean winter temperature.

Figure 45

NSA and winter temperature for the mobile groups

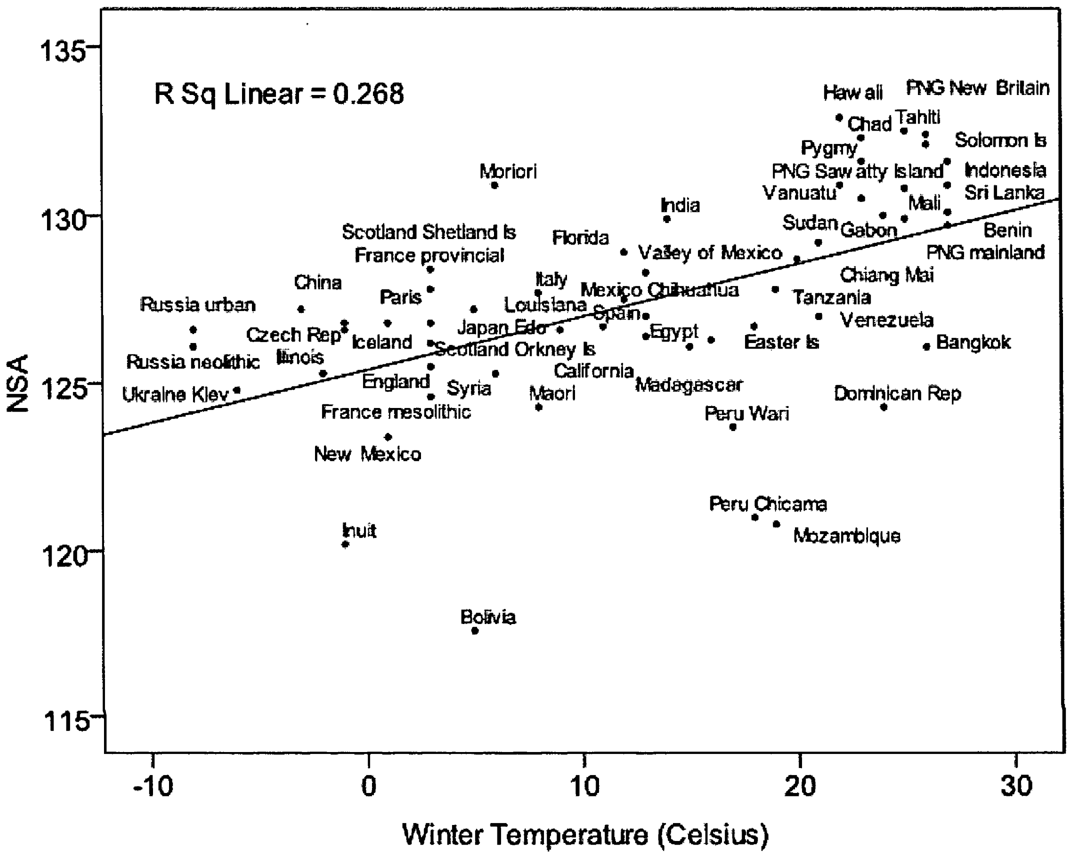


Sedentary Groups and Climate

Similarly, the association between higher NSA and higher environmental temperature is maintained among the sedentary groups (Figure 46), with a correlation of +.548 between NSA and winter temperature.

Figure 46

NSA and winter temperature for the sedentary groups



Chapter 8: Clothing as a Confounding Variable

The extent to which "cultural buffering" from the environment (specifically, the insulatory thermal effect of clothing) may be responsible for a narrowing of the NSA range in agricultural and urban (and, to a lesser extent, sedentary) groups can be assessed by examining the relationship between the use of clothing and those lifestyle categories. In order to examine this relationship, the patterns of clothing use in the sample groups need to be determined, and coded appropriately to enable any trends to be quantified and analyzed statistically.

From a thermal perspective, the most relevant aspects of clothing use are:

1. Whether or not clothing is present and, if present, whether its use is routine;
2. Type of clothing (simple or complex); and
3. Clothing material (woven textiles, or other materials such as animal hides and furs).

Clothing Categories

Various combinations of these thermally-relevant aspects of clothing occur in the sample groups. To reduce complexity of the codings, and to highlight the aspects of most interest here, the varying combinations can, to some extent, be collapsed into a limited number of clothing codes for analysis (Table 35). The first code includes groups where clothing is either absent, not routine, or uncertain. The remaining codes distinguish between whether the type of clothing is predominantly simple or complex, and whether or not the primary clothing materials are woven textiles. This provides a total of five clothing codes (Table 36).

Table 35

Aspects of clothing used to determine clothing codes

Clothing / routine ?	*Simple*	*Complex*	*Textiles*	*Code*
N / N	N	N	N	1
Y / N	S	N	N / T	1
Y / ?	S	N	N / T	1
Y / Y	S	N	N	2
Y / Y	S	N	T	3
Y / Y	S	C	T	3
Y / Y	N	C	N	4
Y / Y	S	C	N	4
Y / ?	N / S	C	N	4
Y / Y	N	C	T	5

Table 36

Description and examples of the five clothing codes

Clothing Code	*Clothing Category*	*Notes and Examples*
1	None / not routine	Includes groups where the routine use of clothing is unlikely or not certain (e.g., Philippine Negritos)
2	Simple / non-woven	Draped non-woven garments only, made for instance from leaves, bark or animal skins (e.g., Khoikhoi)
3	Simple / textiles	Mixed category, mainly draped cloth garments, but can include additional fitted items (e.g., Bantu groups)
4	Complex / non-woven	Fitted +/- multi-layered garments worn routinely, made typically from animal skins (e.g., Aleutians, Sami)
5	Complex / textiles	Routine use of clothes comprising primarily or exclusively complex woven garments (e.g., Aymara)

Group Codes

The next step is to assign one of these five clothing codes to each of the sample groups (restricted to samples with $n \geq 10$, where the mean NSA may be considered more reliable and for compatibility with the economic and mobility coding used in the previous chapter). Murdock (1981) uses only a single clothing code—weaving of cloth on a loom or frame—so ethnographic descriptions from other sources (e.g., Levinson 1998) were consulted in determining the most appropriate clothing codes for the group samples. These are listed for the 86 groups in Table 37.

Table 37

Clothing codes for the 86 sample groups

Country / group	*n*	Clothing / routine?	Simple	Complex	Textiles	Code
AFRICA						
Algeria (Berber)	28	Y / Y	N	C	T	5
" (epipalaeolithic)	25	O /O	O	O	N	
Angola	11	Y / Y	S	C	T	3
Benin	10	Y / Y	S	C	T	3
Bushmen	35	Y / ?	S	N	N	1
Canary Islands	223	Y / Y	S	C	T	3
Central African Rep.	5	Y / Y	S	N	N	
Chad	10	Y / Y	S	C	T	3
Congo	6	Y / Y	S	C	T	
Egypt	136	Y / Y	S	C	T	3
Equatorial Guinea	2	Y / Y	S	N	T	
Ethiopia	5	Y / Y	S	N	T	
Gabon	25	Y / Y	S	N	T	3
Gambia	2	Y / Y	N	C	T	
Ghana	2	Y / Y	N	C	T	
Guinea	2	Y / Y	N	C	T	
Ivory Coast	1	Y / Y	N	C	T	

Madagascar	62	Y / Y	S	C	T	3
Mali	53	Y / Y	N	C	T	5
Morocco (Berber)	18	Y / Y	N	C	T	5
" (epipalaeolithic)	41	O / O	O	O	N	
Mozambique	10	Y / Y	N	C	T	3
Niger	43	Y / Y	S	C	T	3
Nigeria	2	Y / Y	N	C	T	
Pygmy	16	Y / N	S	N	N	1
Senegal	8	Y / Y	N	C	T	
Somalia	47	Y / Y	S	C	T	3
South Africa						
" Khoikhoi	22	Y / Y	S	N	N	2
" Xhosa (Bantu)	10	Y / Y	S	C	T	3
" Zulu	2	Y / Y	S	N	N	
Sudan (Nubian)	130	Y / Y	S	N	T	3
Tanzania	161	Y / Y	S	N	T	3
Tunisia	2	Y / Y	N	C	T	
ASIA						
Andaman Islands	81	N / N	N	N	N	1
Bangladesh	2	Y / Y	N	C	T	
China	115	Y / Y	N	C	T	5
India	47	Y / Y	N	C	T	5
Indonesia (total)	11	Y / Y	S	N/C	T	3
" Borneo	3	Y / Y	S	N	T	
" Java	2	Y / Y	S	C	T	
" Sumatra	6	Y / Y	S	C	T	
Iran	6	Y / Y	S	C	T	
Japan						
" Ainu	233	Y / Y	S	C	T	3
" Edo period	251	Y / Y	N	C	T	5
Kampuchea	2	Y / Y	N	C	T	
Laos	2	Y / Y	N	C	T	
Malaysia	3	Y / Y	N	C	T	
" Semang	2	Y / ?	S	N	N	
Nepal	2	Y / Y	N	C	T	
Nicobar Islands	12	Y / ?	S	N	N	1
Okhotsk	19	Y / ?	N	C	N	4
Pakistan	4	Y / Y	N	C	T	
Philippines	92	Y / Y	S	C	T	3
" Negrito	37	Y / ?	S	N	N	1
Siberia	18	Y / Y	N	C	T	5
Sri Lanka	16	Y / Y	N	C	T	5
Syria	15	Y / Y	S	C	T	3
Thailand						
" Bangkok	243	Y / Y	N	C	T	5

" Chiang Mai	214	Y / Y	N	C	T	5
Turkmenistan	4	Y / Y	N	C	T	
Veddah	16	Y / Y	S	N	N	2
Vietnam	16	Y / Y	N	C	T	5
AUSTRALIA						
South Australia	47	Y / N	S	N	N	1
EUROPE						
Armenia	2	Y / Y	N	C	T	
Belgium	6	Y / Y	N	C	T	
Cyprus	2	Y / Y	N	C	T	
Czech Republic	56	Y / Y	N	C	T	5
England	1271	Y / Y	N	C	T	5
Estonia	4	Y / Y	N	C	T	
Finland	2	Y / Y	N	C	T	
France						
" mesolithic	24	Y / ?	S	C	T	3
" neolithic	393	Y / Y	N	C	T	5
" provincial	249	Y / Y	N	C	T	5
" urban (Paris)	102	Y / Y	N	C	T	5
Iceland	146	Y / Y	N	C	T	5
Italy	10	Y / Y	N	C	T	5
Norway	4	Y / Y	N	C	T	
Poland	8	Y / Y	N	C	T	
Russia						
" neolithic	30	Y /Y	N	C	T	5
" urban (Moscow)	16	Y / Y	N	C	T	5
Sami	12	Y / Y	N	C	N	4
Scotland						
" Orkney Islands	83	Y / Y	N	C	T	5
" Shetland Islands	351	Y / Y	N	C	T	5
Spain						
" Balearic Islands	12	Y / Y	N	C	T	5
" Basque	2	Y / Y	N	C	T	
Sweden	2	Y / Y	N	C	T	
Ukraine	10	Y / Y	N	C	T	5
Wales	2	Y / Y	N	C	T	
NORTH AMERICA						
Canada						
" British Columbia	265	Y / Y	S	N	T	3
" Ontario	5	Y / Y	N	C	N	
" St. Lawrence	2	Y / Y	S	C	T	
Dominican Republic	24	Y / ?	S	N	N	1
Greenland	90	Y / Y	N	C	N	4
Guadeloupe	4	Y / Y	S	N	N	
Inuit (Aleutian Is.)	324	Y / Y	N	C	N	4

Mexico	38	Y / Y	S	N	T	3
" Chihuahua	11	Y / Y	S	N	T	3
" Coahuila	16	Y / Y	S	N	N	2
U.S.A. (excl. Alaska)						
" Chumash	78	Y / ?	S	N	N	1
" Florida	306	Y / Y	S	N	T	3
" Illinois	100	Y / Y	S	C	T	3
" Kentucky	129	Y / ?	S	C	N	4
" Louisiana	118	Y / Y	S	C	T	3
" New Mexico	142	Y / Y	S	C	T	3
" New York	13	Y / Y	S	N	N	2
" South Dakota	101	Y / Y	S	N	N	2
PACIFIC						
Easter Island	94	Y / Y	S	N	T	3
Fiji	4	Y / Y	S	N	T	
Guam	2	Y / ?	S	N	N	
Hawaii	12	Y / Y	S	N	T	3
Kiribati	4	Y / Y	S	N	N	
Marquesas Islands	2	Y / N	S	N	T	
New Zealand						
" Maori	20	Y / Y	S	N	T	3
" Moriori	25	Y / ?	S	N	N	1
PNG						
" West Papua	18	Y / ?	S	N	N	1
" New Britain	31	Y / Y	S	N	N	2
" (unspecified)	10	Y / Y	S	N	N	2
Solomon Islands	20	Y / Y	S	N	N	2
Tahiti	11	Y / Y	S	N	T	3
Tonga	4	Y / Y	S	N	T	
Vanuatu	76	Y / Y	S	N	T	3
SOUTH AMERICA						
Argentina	108	Y / Y	S	C	T	3
Bolivia	33	Y / Y	N	C	T	5
Brazil	9	Y / Y	S	N	N	
Chile	49	Y / Y	S	C	T	3
Ecuador	193	Y / ?	S	N	N	1
Peru						
" Anton site (Wari)	105	Y / Y	S	C	T	3
" Chicama	106	Y / Y	S	C	T	3
Surinam	4	Y / Y	N	C	T	
Venezuela	68	Y / Y	N	C	T	5
Tierra del Fuego						
" Fuegian	18	Y / ?	S	N	N	1
" Ona	2	Y / Y	S	N	N	
" Yahgan	14	Y / N	S	N	N	1

Clothing Level and Lifestyle

The distributions of clothing codes in the economic and mobility categories can now be examined, looking for any trends in the overall levels of clothing use and whether there exist any marked differences in the patterns of thermally-relevant aspects (type—simple or complex—and materials—textiles of not).

Clothing and Economy

The frequencies of the clothing codes in the three economic categories (forager, agricultural, urban) are listed in Table 38 and their distributions are shown in Figure 47.

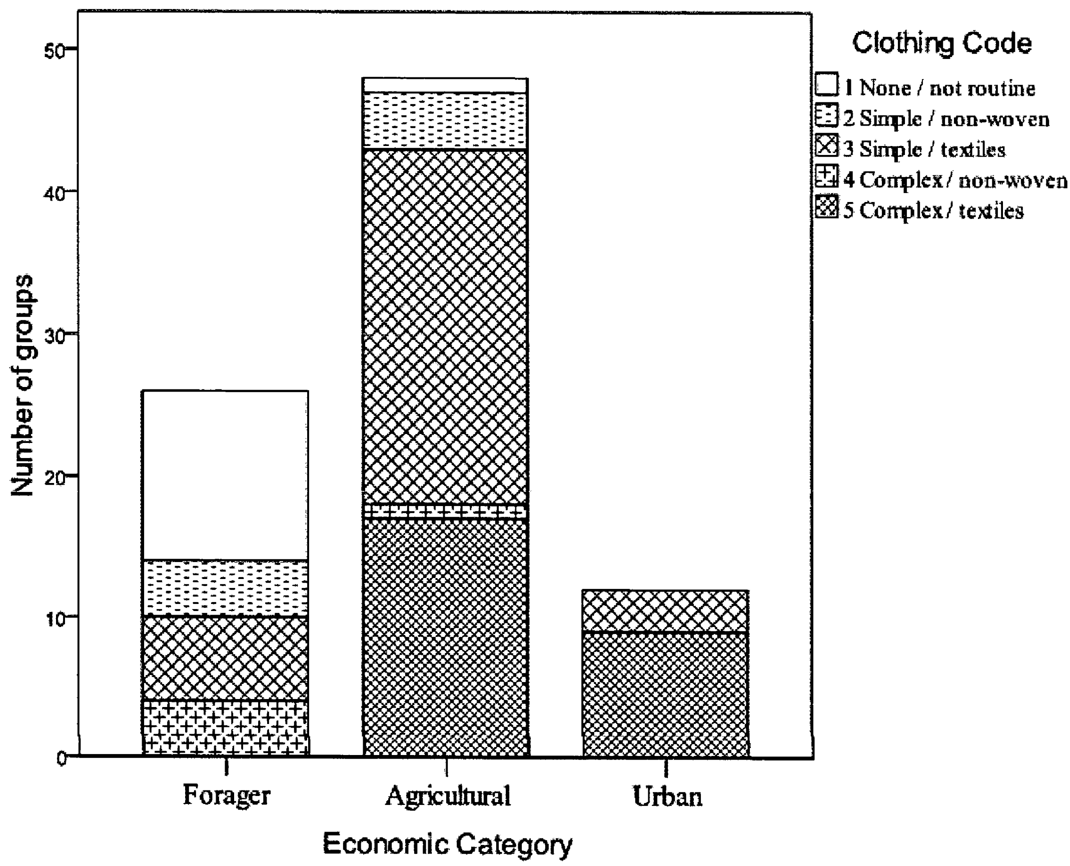
Table 38

Frequencies of clothing codes in the economic categories

Clothing Code	*Economic Category*			*Totals*
	Forager	*Agricultural*	*Urban*	
1	12	1	0	13
2	4	4	0	8
3	4	1	0	5
4	6	25	3	34
5	0	17	9	26
Totals	26	48	12	86

Figure 47

Distributions of clothing codes in the economic categories



The first trend to note is that the absence or non-routine use of clothing is limited almost entirely to forager groups; the one exception occurs with a predominantly agricultural sample (the Dominican Republic, where the main indigenous group, the Taíno, were habitually naked but wove cotton for other items such as mats and ropes). Forager groups are also distinguished from agricultural and urban groups by an absence of complex clothing made of woven textiles (although quite a number of forager groups use simple—i.e., draped, single-layer—garments made of woven fibres (whether wild or cultivated). Overall, forager groups are characterized by a minimal or reduced level of thermally-effective clothing and so, in this important regard, utilize substantially less "cultural buffering" from the climate than agricultural or urban groups.

The next major trend is the dominance of woven fabrics in the agricultural and urban groups (with the latter using exclusively textile garments). The thermal significance of this is that the flexibility and "breathability" of woven garments allows for the continuous use of at least some clothing in all environments (including the warmer and more humid climates of the Holocene), maintaining a more uniformly warm microenvironment around the body.

Agricultural and urban groups are distinguished by differing relative proportions of simple and complex clothing: the majority (60%) of agricultural groups using predominantly simple clothing, and the majority (75%) of urban groups using complex clothes.

The clear overall trend for clothing in the economic categories is a far greater use of clothing in agricultural and urban groups than in the forager groups, and for greater use of more thermally-effective clothing in agricultural and (especially) urban groups. These differing distributions of clothing codes in the economic categories are statistically significant, using chi-square tests (Table 39). In terms of clothing as "cultural buffering" from the environment, the transitions from forager to agricultural, and from agricultural to urban, economies are each associated with substantial increases in their degrees of insulation from the thermal stresses of climatic variation.

Table 39

Results of chi-square tests for clothing and economy

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	52.495[a]	8	.000
Likelihood Ratio	58.011	8	.000
N of Valid Cases	86		

a. 10 cells (66.7%) have expected count less than 5. The minimum expected count is .70.

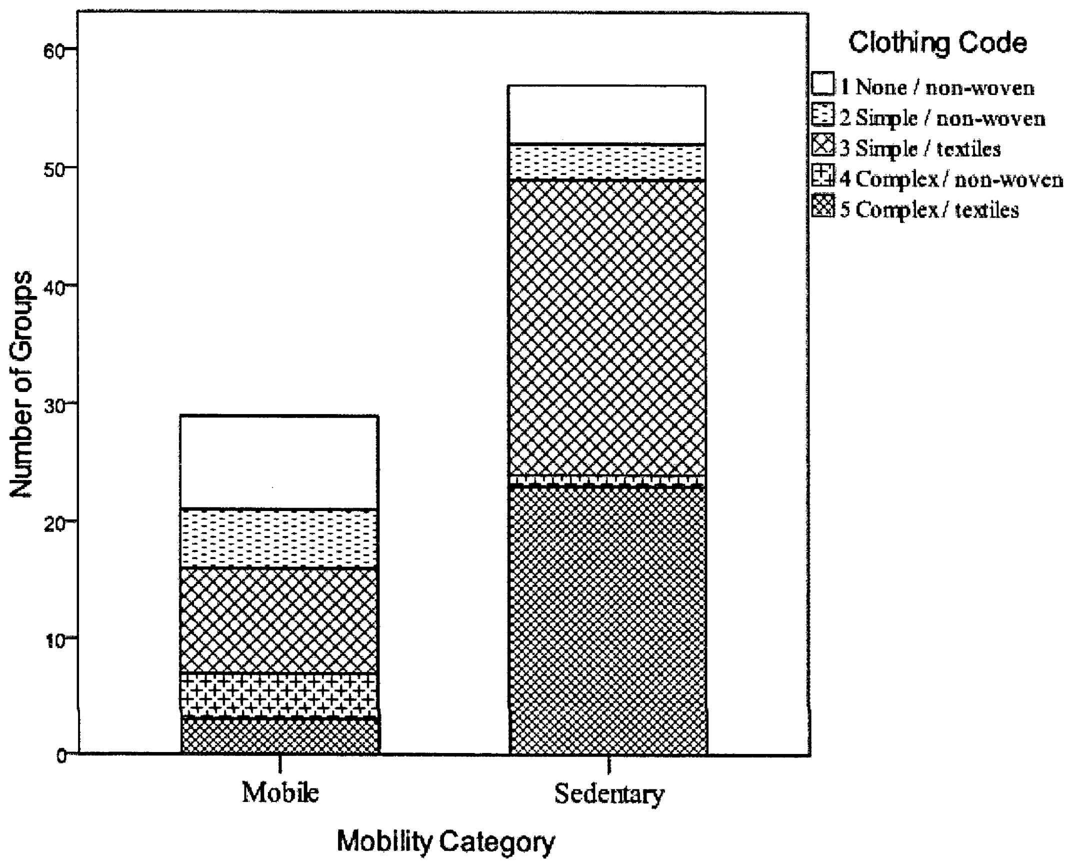
Clothing and Mobility

The distributions and frequencies of clothing codes in the two mobility categories are shown in Figure 48 and Table 40 respectively, and results of chi-square tests in Table 41.

Compared to the distributions for economic categories, the differences between mobile and sedentary groups are less striking but nonetheless significant. The absence or non-routine use of clothing is more commonplace among mobile groups, and the routine use of clothing of any description is more common among sedentary groups (91%, *vs.* 72% for mobile groups). Simple clothing is equally common in mobile and sedentary groups (48% and 49% respectively), whereas complex clothing is more common in sedentary groups (42%, *vs.* 24% in mobile groups).

Figure 48

Distributions of clothing codes in the mobility categories



Overall, there is a marked trend for both more use of clothing in general, and more use of complex clothing, among the sedentary groups. These trends are not as strong as for the economic categories, consistent with the less prominent trends in NSA variation between the mobility categories compared to economic categories, as shown in the previous chapter.

Table 40

Frequencies of clothing codes in the mobility categories

Clothing Code	*Mobility Category*		*Totals*
	Mobile	*Sedentary*	
1	8	5	13
2	5	3	8
3	4	1	5
4	9	25	34
5	3	23	26
Totals	29	57	86

Table 41

Results of chi-square tests for clothing and mobility

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.781[a]	4	.001
Likelihood Ratio	19.129	4	.001
N of Valid Cases	86		

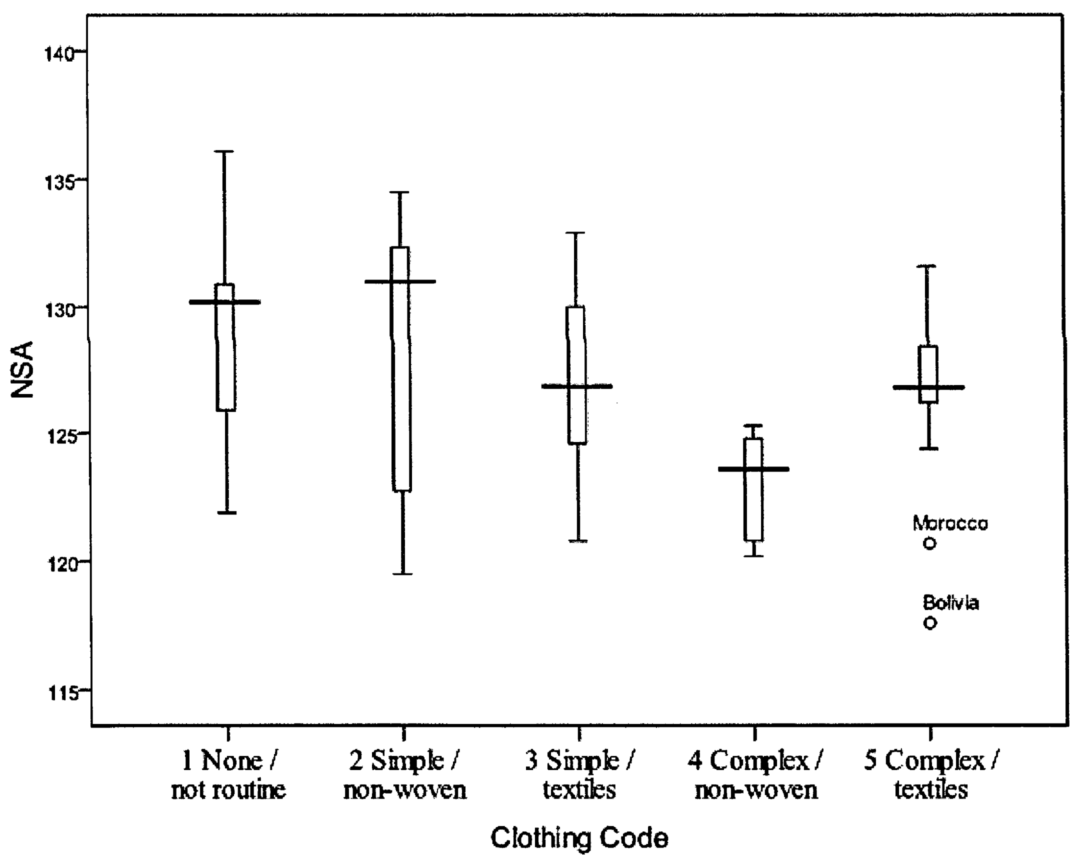
a. 4 cells (40.0%) have expected count less than 5. The minimum expected count is 1.69.

Clothing and NSA

The distributions of the group NSA means among the five clothing codes are shown in Figure 49.

Figure 49

NSA variation among the clothing codes



Two main trends are evident: first is the markedly reduced range in NSA associated with complex clothing, and the second is a slight reduction in average

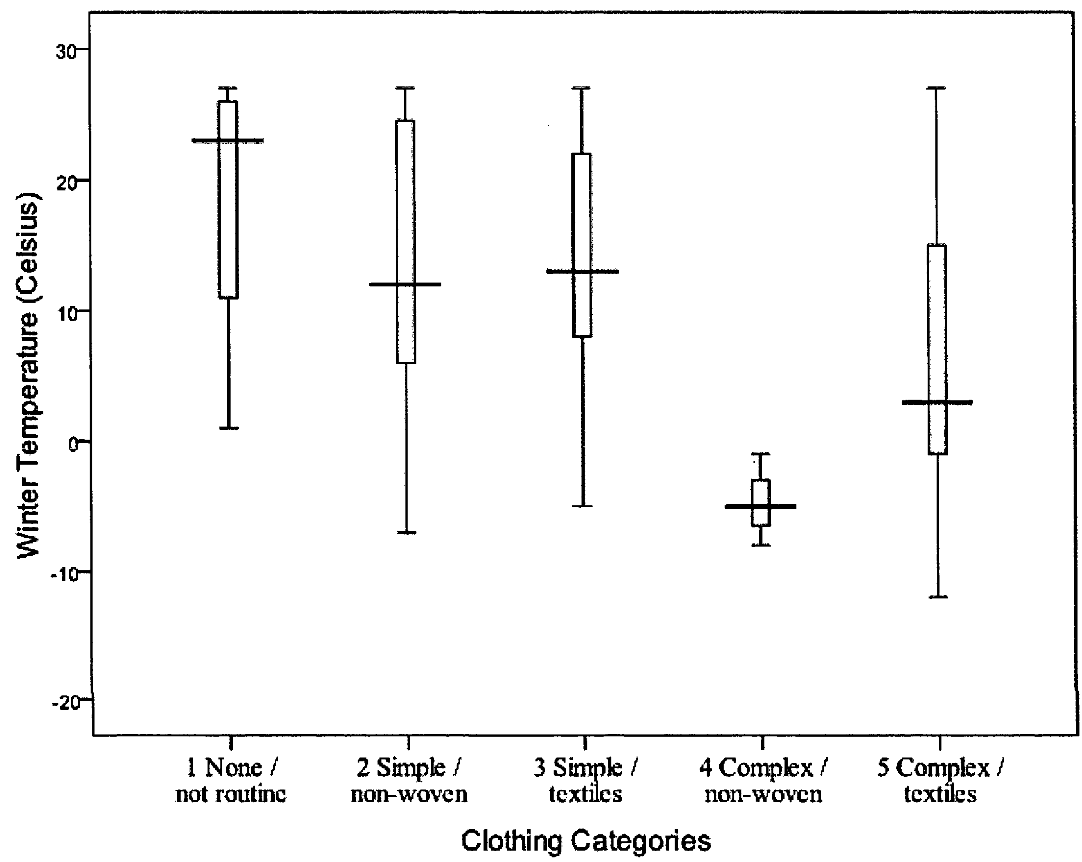
NSA with greater use of clothing. It is the first trend which is more prominent: the narrowing of the NSA range with complex clothing, reflecting more effective buffering from climate. The second trend—a slightly lower NSA with greater use of clothing—probably reflects an underlying climate effect (with cooler climates associated with more use of clothing and also a lower NSA). Another trend worth noting concerns the use of woven textiles for clothing: for both simple and complex clothing, there is a narrowing of the NSA range associated with the use of woven materials.

Clothing and Climate Trends

Comparing the environmental temperature ranges associated with the clothing codes (Figure 50), it becomes apparent that the narrowing of the NSA range with complex clothing cannot be attributed to a narrower climatic range: on the contrary, complex clothing is used not only in cooler climates but also across a greater range of mean winter temperatures. The small number of groups using non-woven complex clothing (such as the Ainu and Sami) constitute a specialized case: forager groups using hides and furs for portable warmth in cold environments. Another trend to note here is the lower mean winter temperatures associated with the use of complex clothing, reflected in the slightly lower NSA among these groups (Figure 49, page 139).

Figure 50

Winter temperature variation for the clothing codes



Climate, Clothing and NSA Trends

The narrowing in the range of NSA associated with the transitions from forager to agricultural and urban economies and, to a lesser extent, the transition from a mobile to a sedentary lifestyle, is mirrored by a similar narrowing of the NSA with greater use of thermally-effective clothing. The major trend in NSA variation associated with these differing lifestyles is attributable to this "cultural buffering", due probably in large part to the known insulatory effect of clothing. The role of the latter as a "confounding" variable in the observed relationships between NSA and lifestyle is evident in the strong association between economic categories and the extent to which thermally-effective clothing is used among the forager, agricultural and urban groups. An underlying climate effect on NSA (accompanying the climatic variation in body shape documented in the literature) is discernible despite the buffering effect of clothing, with a greater use of clothing in cooler climates associated with a reduction in mean NSA.

These analyses underline the predominant thermal basis of NSA variation at the population level, due to the effects of both climate and clothing. The important (and unexpected) finding here is the narrowing of the range of NSA variation associated with the economic transitions to agricultural and urban lifestyles which appears not otherwise explicable but which, when the confounding influence of clothing is taken into account, is entirely predictable on thermal grounds (at least in retrospect).

With regard to late Pleistocene hominins, insofar as the distinctly low NSA of Neanderthals (compared to modern humans) constitutes further evidence for a strong climatic influence on their body shape, it is also evidence for a reduced use of thermally-effective clothing among Neanderthals. In other words, the sensitivity of their morphology to climate points to considerable cold exposure, which in turn suggests relatively less "cultural buffering". Conversely, the existence of marked thermal trends in the NSA among the modern human groups sampled here (trends attributable both to climate and the use of clothing) suggests that a higher average

NSA provides indirect evidence for substantial use of thermally-effective clothing among fully modern humans in the cold environments of late Pleistocene Eurasia.

Chapter 9: Multiple Regression Analysis

Multiple regression analysis provides a technique for assessing the relative importance of the various independent variables examined in preceding chapters—climate, clothing, economy and mobility—in affecting variation in the NSA (the dependent variable). The results of the correlation analyses indicate that climate is a dominant factor, with clothing and the other lifestyle variables (economy and mobility) exerting a secondary influence on NSA variation at the population level. The choice of regression method—hierarchical in this case, rather than standard or stepwise regression—is based on theoretical grounds, with hierarchical regression being favoured since it allows an assessment not only of the strength of the climatic influence, but also the additional influence of clothing levels and lifestyle after controlling for the influence of climate.

Statistical Issues

The main issues with multiple regression include the need for adequate sample size and a minimum number of independent variables, the extent of multi-collinearity between the independent variables, sensitivity to outliers, and an adequate check on the distribution of residuals (the differences between predicted and obtained scores) to ensure that these meet requirements for normality, linearity and homoscedasticity (Pallant 2001: 136-137, Tabachnick and Fidell 2001: 117-122).

Selection of Independent Variables

The need to minimize the number of independent variables leads to selection of a single climatic variable which, together with the three other variables—clothing, economy and mobility—results in an acceptably small number of independent variables (four) in the analysis. The only choice to be made concerns which of the climate variables is most relevant in the present context, or which is likely to have the greatest predictive power. Considering the foregoing results of correlation tests between NSA and the various climatic indices, and considering also the theoretical importance of choosing the most physiologically-relevant climatic index or proxy, mean winter temperature was selected over latitude and mean annual or summer temperature. The four independent variables therefore are:

1. Winter temperature: mean January or July monthly temperature (°C), data from local weather stations as used in the preceding analyses;
2. Clothing, coded as in Chapter 8:
    1. None / not routine / uncertain;
    2. Simple / non-woven garments;
    3. Simple/textiles;
    4. Complex / non-woven; and
    5. Complex / textiles.
3. Economy, coded as in Chapter 7:
    1. Forager (predominantly, includes fishing);

2. Agricultural (includes horticultural and pastoralist); and

3. Urban.

4. Mobility, coded as in Chapter 7:

1. Mobile (excluding seasonal sedentism); and

2. Sedentary (including seasonal sedentism).

Multicollinearity

The programme used for these analyses (SPSS® Graduate Pack 16.0 for Windows) generates a table of correlations between the variables, enabling a check on the strength of correlation between the dependent variable (the NSA, in this instance) and the independent variables, as well as between each of the independent variables (four in this instance).

Sample Size

Multiple regression requires relatively large sample sizes to ensure generalisability of results, and various formulæ are suggested by different statisticians to determine the recommended minimum sample size. The number of independent variables is critical, with Tabachnick and Fidell (2001: 117) advising either:

1. $n \geq 50 + 8m$, or
2. $n \geq 104 + m$ (where m is the number of independent variables).

In terms of the number of sample groups, the NSA database is marginal with regard to meeting the sample size criterion, especially if (as should be the case) the samples with small numbers of femora are excluded as having unreliable mean values (given the wide intra-group variation in NSA). If a minimum group sample size of $n \geq 10$ is chosen, for example, the total sample size for the regression analysis is 82, which barely satisfies the first of Tabachnick and Fidell's formulæ and fails to satisfy the second. A preferred alternative, then, is to base the regression analysis on the individual NSA values in each of the 82 groups, which yields a very adequate sample size of $n = 8{,}057$.

Outliers

The presence of outliers is not necessarily a problem, depending upon their values and distribution—if the outliers have scores that are not unexpected in a given dataset, and providing that all of the outliers are reasonably evenly distributed so as not to distort the results, they need not be excluded. The SPSS® regression programme generates a list of outliers (defined as those cases with standardized residuals of > 3.3 or < -3.3) which can be examined on a case-by-case basis, and the overall distribution of outliers can be ascertained by inspecting the residuals scatterplot generated by the programme. Given the fact that the NSA manifests a wide range of variation at the individual level, with values of ≤ 110° and ≥ 140° not extremely uncommon, a considerable number of outliers can be anticipated, and their values and distributions checked.

Normality, Linearity and Homoscedasticity

The extent to which these assumptions of multiple regression are satisfied can be assessed by inspection of the normal probability plot and the residuals scatterplot, which show the relationships between predicted and obtained scores. *Normality* refers to whether the obtained scores are spread around the predicted values in a pattern that approximates a normal distribution; *linearity* can be confirmed by the absence of marked curvature in their pattern of distribution, and *homoscedasticity* by checking that the variance between obtained and predicted scores is approximately the same across the full range of predicted values. Therefore, checking the normal probability plot and inspecting the residuals scatterplot are the keys to assessing whether the analysis meets all of these assumptions.

Input Data for the Regression Analysis

The individual NSA values among each of the 82 group samples comprise the scores on the dependent variable in the analysis, and scores on each of the four independent variables comprise the respective scores or codes on the winter temperature, clothing, economy and mobility variables as defined at the beginning of this chapter. In this hierarchical analysis using SPSS® linear regression, winter temperature was entered as "Block 1" and the remaining independent variables as "Block 2". The scores on each of the independent variables for the 82 groups included in the analysis are listed in Table 42.

Table 42

Groups with $n \geq 10$ for NSA, and corresponding scores on the four independent variables used in the regression analysis

Country / group	n	Winter Temp. (°C)	Clothing code	Economic code	Mobility code
AFRICA					
Algeria (Berber)	28	11	3	2	1
Angola	11	20	3	2	2
Benin	10	27	3	2	2
Bushmen	35	13	1	1	1
Canary Islands	223	17	3	2	1
Chad	10	23	3	2	2
Egypt	136	13	3	3	2
Gabon	25	24	3	2	2
Madagascar	62	15	3	2	2
Mali	53	25	5	2	2
Morocco (Berber)	18	12	3	2	1
Mozambique	10	19	3	2	2
Niger	43	24	3	2	2
Pygmy	16	23	1	1	2
Somalia	47	27	3	2	1
South Africa - Bantu	10	12	3	2	1
" Khoikhoi	22	12	2	2	1
Sudan (Nubian)	130	23	3	3	2
Tanzania	161	19	3	2	2
ASIA					
Ainu	233	-5	3	1	2
Andaman Islands	81	26	1	1	1
China	115	-3	5	3	2
India	47	14	5	2	2
Japan (Edo period)	251	5	5	3	2
Nicobar Islands	12	27	1	1	1
Okhotsk	19	-5	4	1	1
Philippines	92	26	3	1	1
" Negrito	37	26	1	1	1
Siberia	18	-12	5	2	1
Sri Lanka	16	27	5	2	2
Syria	15	6	3	2	2
Thailand	457	26	5	3	2

Veddah	16	27	2	1	1
Vietnam	16	16	5	2	2
AUSTRALIA					
South Australia	47	11	1	1	1
EUROPE					
Czech Republic	56	-1	5	2	2
England	1271	3	5	2	2
France - mesolithic	24	3	3	1	2
" neolithic	393	1	5	2	2
" provincial	249	3	5	3	2
" urban (Paris)	102	3	5	3	2
Iceland	146	-1	5	2	2
Italy	10	8	5	2	2
Russia - neolithic	30	-8	5	2	2
" urban (Moscow)	16	-8	5	3	2
Sami	12	-5	4	2	1
Scotland	434	3	5	2	2
Spain	12	11	5	2	2
Ukraine (Kiev)	10	-6	5	3	2
NORTH AMERICA					
Canada (B Columbia)	265	3	3	1	1
Dominican Republic	24	24	2	2	2
Greenland	90	-8	4	1	1
Inuit (Aleutian Is.)	324	-1	4	1	2
Mexico (Valley M.)	38	13	3	3	2
" Chihuahua	11	12	3	2	2
" Coahuila	16	12	2	1	1
U.S.A. (excl. Alaska)					
" California	78	13	3	1	2
" Florida	306	12	3	1	2
" Illinois	100	-2	3	1	2
" Kentucky	129	0	3	1	1
" Louisiana	118	9	3	2	2
" New Mexico	142	1	3	2	2
" New York	13	0	2	1	1
" South Dakota	101	-7	2	1	1
PACIFIC					
Easter Island	94	18	3	2	2
Hawaii	12	22	3	2	2
New Zealand (Maori)	20	8	3	2	2
" Moriori	25	6	3	1	2
PNG (mainland)	10	25	2	2	2
" Sawatty Island	18	27	2	1	2
" New Britain	31	26	2	2	2

Solomon Islands	20	26	2	2	2
Tahiti	11	25	3	2	2
Vanuatu	76	22	3	2	2
SOUTH AMERICA					
Argentina	108	10	3	2	1
Bolivia	33	5	3	2	2
Chile	49	8	3	2	1
Ecuador	193	14	1	1	1
Fuegian (unspecified)	18	1	1	1	1
" Yahgan	14	1	1	1	1
Peru (Wari empire)	105	17	3	3	2
" Chicama	106	18	3	2	2
Venezuela	68	21	5	3	2

Check of Assumptions

The SPSS® linear regression output using the above scores on the independent variables (and using individual NSA scores for each group as the dependent variable) includes a correlations table, normal probability plot, residuals scatterplot and a casewise diagnostics table for examining outliers. Before discussing the results of the regression analysis itself, the foregoing output can be used to check the extent to which the analysis satisfies the statistical assumptions.

Correlations

With the exception of winter temperature, the correlation results (Table 43) show only weak correlations between NSA and the independent variables. This in itself is not unexpected given the great range in variation of NSA compared to that of the independent variables. The correlation results in preceding analyses (using group

NSA means) demonstrated that most variation in NSA is not explained by any of these variables: the highest correlations for climate accounting for some 20% of the variance. At the individual level (which applies here, given the use of NSA from individual femora rather than group means), most of the NSA variation may be considered essentially random. The correlation for winter temperature (+.225) here is quite strong in these circumstances—Pallant (2001: 143) suggests that at least ±.3 is preferable—and contrasts with the very weak correlations between NSA and the other independent variables.

Table 43

Correlations between the independent and dependent variables, and descriptive statistics

Variables	*NSA*	*Winter Temp.*	*Clothing*	*Economy*	*Mobility*
Winter T.	.225				
Clothing	.001	-.207			
Economy	.097	.237	.584		
Mobility	.010	-.080	.585	.453	
n	8057	8057	8057	8057	8057
mean	126.4	8.19	4.18	1.92	1.79
SD	5.55	9.47	1.07	0.70	0.41

The total lack of correlation between NSA and clothing in this regression analysis occurs in the context of very low correlations between NSA and all the remaining independent variables, and is attributable to the strong multicollinearity between clothing, economy and mobility. The correlations between these three remaining independent variables range between +.453 and +.585, meaning that they constitute a set of strongly inter-related variables distinct from winter temperature. The correlations between clothing, economy and mobility are nonetheless below the level (±.700) at which deletion of at least one of the variables would be advisable (Tabachnick and Fidell 2001: 84). In the SPSS® programme, screening for severe multicollinearity causing statistical instability is provided by tolerance criteria that automatically exclude variables exceeding the default tolerance limits. The tolerance statistics are listed in the output, with low values (approaching zero) indicating potential problems (Pallant 2001: 143); in this analysis, the tolerance values for winter temperature, clothing, economy and mobility are all quite respectable (.762, .449, .511 and .638 respectively). As a further safeguard, whether collinearity may nonetheless pose difficulties for the analysis can be assessed by examining the collinearity diagnostics feature produced as part of the SPSS® linear regression output. This lists the "condition index" and the associated "variance proportions" on the independent variables for each root (or "dimension") of the analysis. In terms of deciding whether to abort the analysis due to multicollinearity, Tabachnick and Fidell (2001: 85) recommend that provided no dimension has a condition index approaching 30 coupled with at least two variance proportions greater than 0.50, collinearity is not a major problem. The collinearity diagnostics for this analysis show none of the dimensions with a condition index greater than 30, with none having more than one variance proportion greater than 0.50, and so the evident multicollinearity between clothing, economy and mobility does not present an insurmountable difficulty for the analysis.

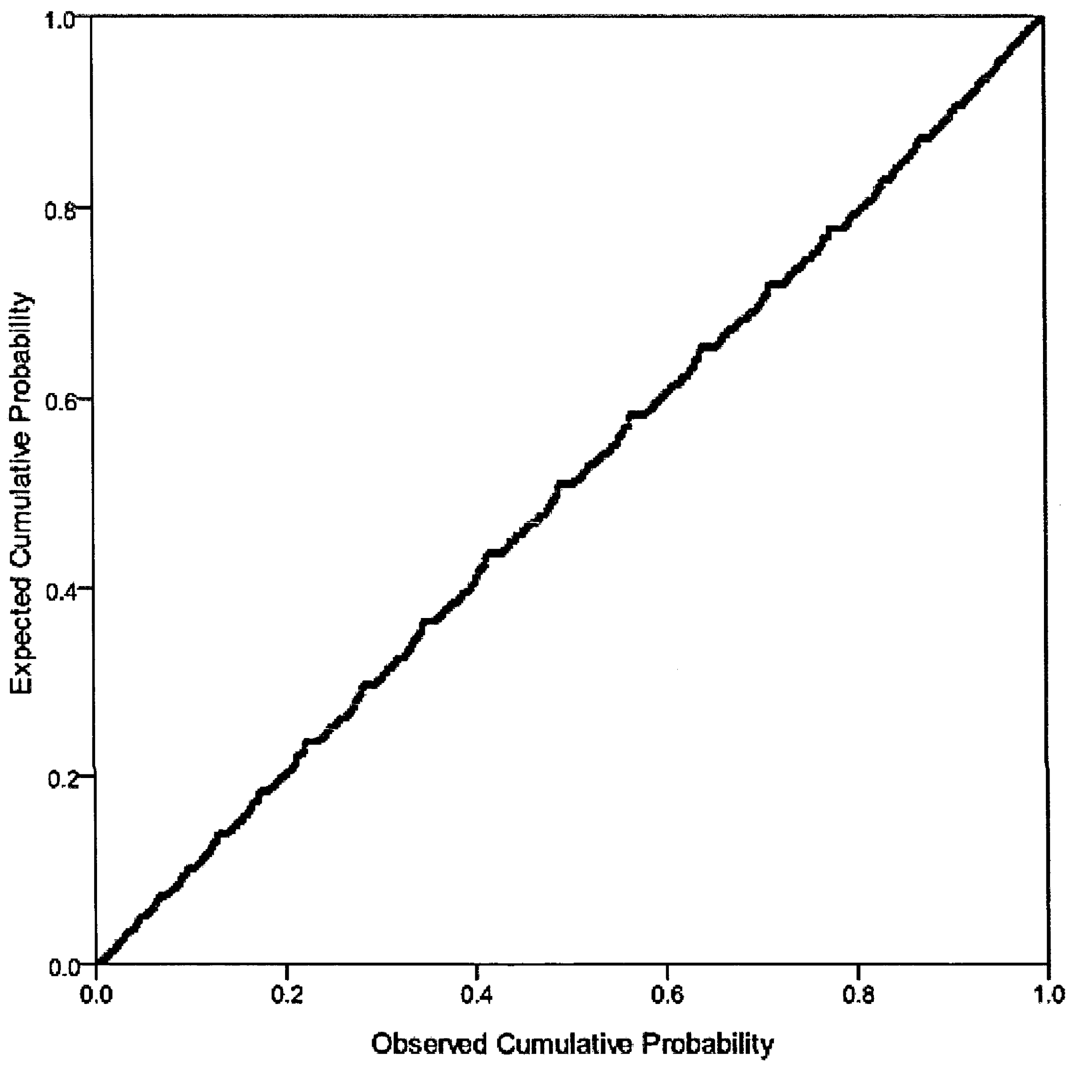
Overall, these correlation results show that winter temperature is likely to prove the most powerful predictor of NSA, and the remaining independent variables together are likely to contribute only a minor additional component (if any). The hierarchical method of regression will allow for an assessment of both the predictive power of climate (winter temperature) and also the relative power of the other independent variables after controlling for the influence of winter temperature.

Normality, Linearity and Homoscedasticity

Normality of residuals is checked by examining both the normal probability plot and the residuals scatterplot in the output. In the normal probability plot, the distributions of expected *vs.* observed residuals should ideally lie in a reasonably straight line, and this condition is clearly satisfied here (Figure 51). In the residuals scatterplot, normality can be assessed by the overall shape of the distributions: ideally, it should be more-or-less rectangular (Pallant 2001: 144), without any major trend towards curvature that would indicate deviation from normality. Lack of normality would not necessarily invalidate the analysis, but would substantially reduce the power of a linear analysis to adequately capture the full extent of the relationships between the dependent and independent variables (Tabachnick and Fidell 2001: 121).

Figure 51

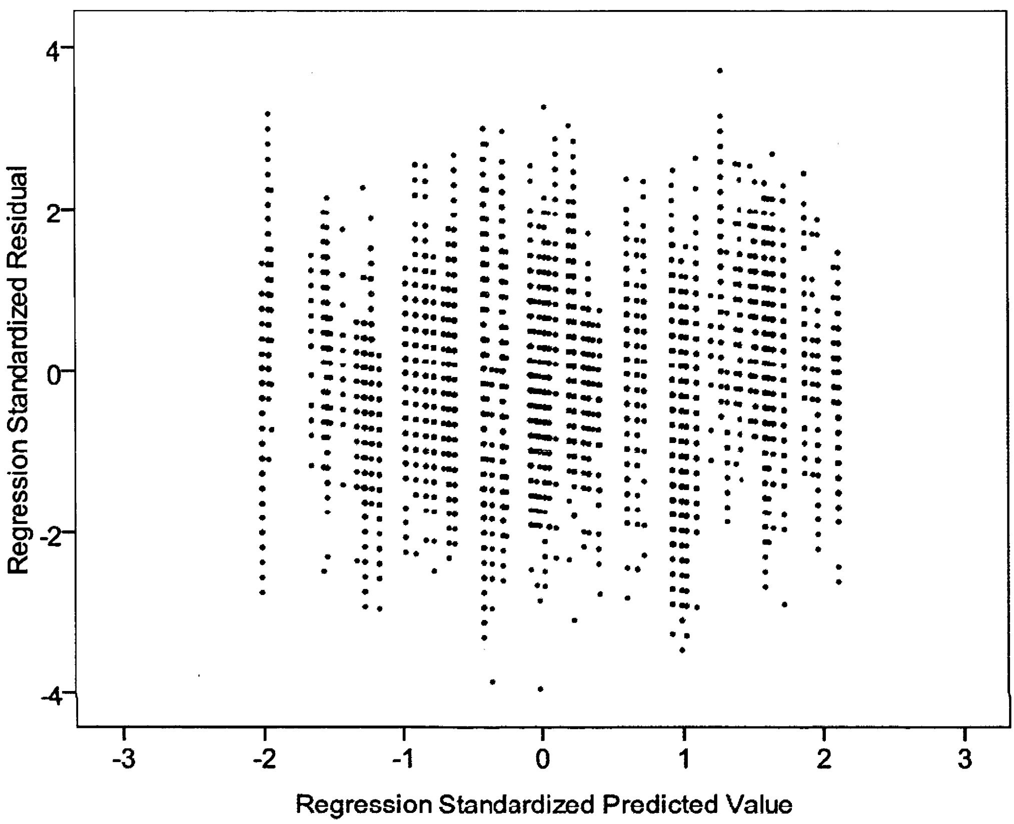
Normal Probability Plot



The overall distribution of residuals in the residuals scatterplot demonstrates an acceptable approximation to a rectangular shape (Figure 52), with the main concentration of scores located centrally, and without a major spread of scores peripherally. This pattern indicates a reasonably normal distribution of the residuals.

Figure 52

Residuals Scatterplot



The residuals scatterplot also indicates no significant deviation from linearity, with no curvature evident in the distribution. Neither is there any indication of heteroscedasticity: the variance between predicted and obtained residuals is reasonably uniform across the full range of predicted values, indicating that the assumption of homoscedasticity is satisfied in this regression analysis.

Outliers

Of the 8,057 cases in the analysis, only 22 emerge as outliers (with standardized residuals greater than ±3.0), and these are listed in Table 44.

Table 44

List of outliers and their standardized residuals

Group / sample	*Case #*	*NSA*	*Predicted value*	*Standard residual*
Canary Islands	300	110	127.58	-3.257
Andaman Islands	2419	148	128.03	3.700
Andaman Islands	2420	145	128.03	3.144
Poundbury	2727	109	125.86	-3.123
Poundbury	3126	109	125.86	-3.123
Poundbury	3236	109	125.86	-3.123
Poundbury	3274	109	125.86	-3.123
Poundbury	3767	108	125.86	-3.308
Poundbury	3799	108	125.86	-3.308
Poundbury	3800	109	125.86	-3.123
Poundbury	3803	109	125.86	-3.123
Greenland	5630	141	123.88	3.172
Florida	6372	110	126.69	-3.092
Argentina	7372	143	126.65	3.030

Bolivia	7493	105	125.93	-3.877
Chile	7509	105	126.38	-3.960
Ecuador	7552	144	126.42	3.256
Peru - Wari	7802	110	127.71	-3.280
Peru - Wari	7809	110	127.71	-3.280
Peru - Chicama	7887	109	127.67	-3.458
Peru - Chicama	7892	111	127.67	-3.087
Peru - Chicama	7897	111	127.67	-3.087

NSA values for all of the outliers are well within the expected limits for a very large sample, and there are no theoretical grounds for excluding any of them from the analysis. The high proportion of Poundbury outliers merely reflects the very large Poundbury sample size (n = 1,271). Some of the samples contributing outliers are worth noting: high outliers from the Andaman Islands and Ecuador, for instance, both corresponding to warm environments, and low outliers from the Americas (especially South America). All the Poundbury outliers have low NSA values, not unexpected from the English sample. The high Greenland outlier is anomalous, as is the high mean NSA of the whole Greenland sample, as mentioned in Chapter 6. Low outliers from both the Canary Islands and Florida, and the high outlier from Argentina, are a little unexpected, but each of these derives from a reasonably large sample (n = 223, 306 and 108 respectively). The distribution of outliers has no obvious adverse impact on the pattern of residuals in the residuals scatterplot (Figure 52, page 156).

Results

The SPSS® linear regression programme generates a "model" (in the case of hierarchical regression, a model composed of a number of "blocks"), with the overall power of the model to predict scores on the dependent variable indicated by the R^2 (or r^2) value. It also provides analysis of variance (ANOVA) to assess the statistical significance of the results, and standardized β coefficients to compare the contributions from each independent variable. The results of this hierarchical regression analysis are shown in Table 45.

Table 45

Summary table of multiple regression results

	Block 1	*Block 2*	*β*	*Sig.*
Dependent Variable	NSA	NSA		
Independent Variable(s)	Winter T.	Winter T.	.227	<.001**
		Clothing	.037	.024*
		Economy	.023	.130
		Mobility	-.004	.790
R	.225	.231		
R^2	.051	.053		
R^2 change		.03**		
Significance levels:			*$p < .05$, **$p < .001$	

Evaluation of Model

The R^2 values indicate that only a small proportion of the total variance in NSA is explained by this analysis—5.1% with winter temperature as the sole independent variable, and 5.3% with the addition of the remaining independent variables (clothing, economy and mobility). This is a disappointing result, but not altogether unexpected given the extent of variability in the NSA. Compared to the dependent variable, the independent variables have very little variation, and this greatly reduces the power of the analysis to detect relatively small trends in the NSA that may exist at the group or population level. This is seen, for instance, in comparing the standard deviations in Table 43 (page 152): 5.55 for NSA, 9.47 for winter temperature, but only 1.07, 0.70 and 0.41 for clothing, economy and mobility respectively. Nevertheless, the results overall reach statistical significance, particularly in relation to the climate variable (winter temperature). Even though the addition of the other three independent variables (in Block 2) adds merely 0.3% to the variance explained, these variables—clothing, economy and mobility—together increase the predictive power of the model by a statistically significant amount after controlling for the effect of climate.

Evaluation of Independent Variables

Two of the β coefficients reach statistical significance: winter temperature ($p < .001$) and clothing ($p < .05$). However, these β coefficients represent only "the *unique* contribution of each variable, when the overlapping effects of all other variables are statistically removed" (Pallant 2001: 149, emphasis added). As such, the β coefficient will under-represent the overall contribution of each independent variable, especially where (as in this analysis) there exists considerable collinearity between the independent variables. Moreover, as mentioned above, the possibility that the relatively low standard deviations (and skewed frequency distributions) of the clothing, economy and mobility variables contribute to their weak predictive power (and may also exert a disproportionate influence on their relative strengths) must be taken into consideration when interpreting these results.

Despite its limitations, this regression analysis underlines a dominant influence of climate on NSA variation at the population level compared to the effects of clothing, economy and mobility. The effect of clothing is small yet significant in its own right, but neither economy nor mobility make a statistically significant unique contribution. However, the correlation results indicate that collinearity between clothing, economy and mobility is substantial, which compromises assessment of the relative contributions made by these variables to the explanatory power of the analysis. On the other hand, analyses in the preceding chapters suggest that any effects of economy and mobility on NSA variation may be mediated, to some extent, by their systematic association with levels of clothing. Insofar as the regression results for clothing and lifestyle variables warrant interpretation, the emergence of clothing as a statistically significant independent variable in the analysis may lend some (qualified) support to the view that the use of clothing might act as a "confounding" factor in observed trends in the NSA associated with sedentism and with the transitions to an agricultural or urban lifestyle among modern human groups.

Chapter 10: Anatomical Issues

The assembling of a global NSA database enables a number of unresolved anatomical questions concerning the NSA to be addressed, in addition to the questions regarding the possible influence of thermal and lifestyle factors (climate, clothing, economy and mobility) on NSA variation at the population level which have been explored in the preceding chapters. These anatomical issues are:

1. *Gender differences*: the prevailing medical belief is that the NSA tends to be slightly lower in females than males, although Anderson and Trinkaus (1998, pp. 282-283) found no evidence for a consistent gender difference in their (limited) sampling of 17 groups;

2. *Bilateral* asymmetry: whilst considerable ($\geq 5°$) asymmetry at the individual level is not uncommon, evidence for a consistent difference between left and right sides at the group or population level has not emerged (ibid., p. 283); and

3. *Age effect*: from its high neonatal values, the NSA declines markedly in childhood, reaching stable adult values by late adolescence, and it is generally thought that the NSA may also decline slightly with advanced age (e.g., > 60 years).

Gender Differences

Only 33 of the group samples have information on gender, with only the Thai (Bangkok and Chiang Mai) samples—recent skeletal collections from known persons—providing definite gender determination. For the remaining samples, reliance is placed on the gender assigned to the specimens by other researchers at the various institutions based on anatomical assessments, mainly involving established criteria for the gender determination of associated skeletal elements (e.g., the cranium and pelvis) rather than the femora (for which there are no widely-accepted anatomical indicators of gender besides femoral head diameter).

In the present analyses, the gender assigned to the specimens by the institutions are used in the analyses with additional, separate analyses of gender differences for the Thai samples (and also the large Poundbury sample).

Total Sample

Gender results for the combined total sample (n = 3,348) from the 33 groups with known or assigned gender are shown in Table 46 and Figure 53.

The results clearly indicate no significant gender difference in the NSA using this large combined sample, with a mean difference of merely 0.04° and identical median NSA values for males and females of 125°.

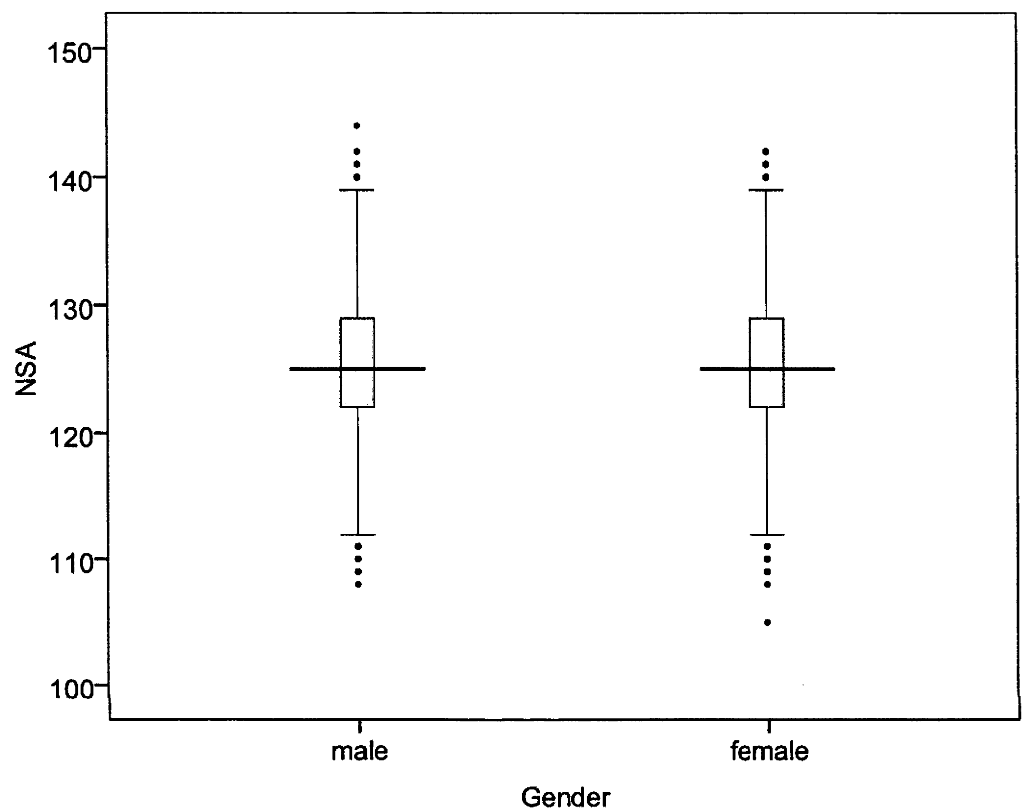
Table 46

Descriptive statistics for NSA and gender using the total sample

	Male	*Female*	
n	1882	1466	
total *n*			3348
% of total	56.2%	43.8%	100
mean NSA	125.21	125.17	
difference			0.04
median	125	125	
minimum	108	105	
maximum	144	142	
range	36	37	
standard deviation	5.554	5.687	
standard error of mean	.128	.149	
95% confidence interval for mean (lower bound)	124.96	124.88	
95% confidence interval for mean (upper bound)	125.46	125.47	
t-test (df 3346):			
significance (2-tailed)			.851
% of NSA variance explained by gender			0.001%

Figure 53

Distributions of NSA by gender using the total sample



33 Group Samples

Another method for investigating gender differences in this total sample is to examine the gender differences in each of the 33 groups, comparing both the numbers of groups with a higher mean for males than females and also the magnitude of any gender differences in NSA at the group level (Table 47).

Table 47

Mean male and female NSA for the 33 group samples

Country / group	n	Male NSA	Male n	Female NSA	Female n	Difference (female - male)	
AFRICA							
Bushmen	29	126.2	10	126.3	19	+ 0.1	
Pygmy	8	134.5	4	128.3	4	- 6.2	*
Somalia	43	125.9	41	120.0	2	- 5.9	*
Sudan (Nubian)	9	129.8	6	131.3	3	+ 1.5	
Tanzania	161	127.8	112	127.7	49	- 0.1	
ASIA							
Ainu	111	126.6	69	124.0	42	- 2.6	
Andaman Islands	39	135.4	25	137.4	14	+ 2.0	
India	20	128.6	14	130.8	6	+ 2.2	
Negrito	5	125.0	2	125.3	3	+ 0.3	
Sri Lanka	16	129.0	10	130.8	6	+ 1.8	
Thailand							
“ Bangkok	137	126.4	95	126.3	42	- 0.1	
“ Chiang Mai	214	129.3	106	128.9	108	- 0.4	
Veddah	8	132.0	2	131.3	6	- 0.7	
AUSTRALIA							
South Australia	38	130.9	16	128.8	22	- 2.1	
EUROPE							
Czech Republic	12	127.8	8	128.8	4	+ 1.0	
England	1271	125.4	591	125.5	680	+ 0.1	
France	34	125.9	18	126.1	16	+ 0.2	
Russia	4	120.5	2	121.5	2	+ 1.0	
Sami	12	125.3	6	125.2	6	- 0.1	
NORTH AMERICA							
Canada	79	123.8	59	124.0	20	+ 0.2	
Greenland	8	128.3	4	127.0	4	- 1.3	
Guadeloupe	4	119.0	2	122.5	2	+ 3.5	
Inuit (Aleutian Is.)	322	120.0	200	120.6	122	+ 0.6	
USA (excl. Alaska)							
“ Illinois	100	125.1	71	125.9	29	+ 0.8	
“ Kentucky	124	123.6	72	123.4	52	- 0.2	
“ New Mexico	142	122.5	69	124.3	73	+ 1.8	
“ South Dakota	101	120.3	65	120.1	36	- 0.2	

PACIFIC							
Easter Island	17	126.4	5	126.8	12	+ 0.2	
Solomon Islands	10	131.3	6	130.5	4	- 0.8	
SOUTH AMERICA							
Bolivia	4	123.0	1	123.3	3	+ 0.3	
Chile	6	125.3	4	108.0	2	- 17.3	*
Peru	108	122.2	56	119.6	52	- 2.6	
Tierra del Fuego	7	122.0	1	121.7	6	- 0.3	
Summary							
female > male	17/30						
average difference						+0.2	
* *excluded outliers* (small samples, gender difference > 5.0)							

Of the 33 groups, there are three obvious outliers in terms of the magnitude of the gender difference: Pygmy (n = 8), Somalia (n = 43) and Chile (n = 6). Given the low average magnitude of the gender differences among the other groups, these small samples can be excluded as unreliable (the Somali sample comprising 41 male femora but only two female femora). Comparing the remaining 30 groups, the female NSA is slightly higher—*not* lower—in the majority (17/30) of groups, but the average difference is very small (0.2°). Given the sampling and measurement issues, and the range of group differences and trends, it may be concluded that this method of examining the total sample by group reveals no significant gender difference.

If the number of groups is restricted to samples comprising at least five femora for each sex (Table 48), again there are slightly more groups (11/20) where the female NSA is higher (rather than lower) than the male NSA and the average difference (0.8°) can be considered insignificant.

Table 48

Gender differences in mean NSA among samples with $n \geq 5$ for both sexes

Country / group	n	Male		Female		Difference (female - male)
		NSA	n	NSA	n	
Ainu	111	126.6	69	124.0	42	- 2.6
Andaman Islands	39	135.4	25	137.4	14	+ 2.0
Australia	38	130.9	16	128.8	22	- 2.1
Bushmen	29	126.2	10	126.3	19	+ 0.1
Canada	79	123.8	59	124.0	20	+ 0.2
Easter Island	17	126.4	5	126.8	12	+ 0.2
England	1271	125.4	591	125.5	680	+ 0.1
France	34	125.9	18	126.1	16	+ 0.2
India	20	128.6	14	130.8	6	+ 2.2
Inuit (Aleutian Is.)	322	120.0	200	120.6	122	+ 0.6
Peru	108	122.2	56	119.6	52	- 2.6
Sami	12	125.3	6	125.2	6	- 0.1
Sri Lanka	16	129.0	10	130.8	6	+ 1.8
Tanzania	161	127.8	112	127.7	49	- 0.1
Thai. Bangkok	137	126.4	95	126.3	42	- 0.1
" Chiang Mai	214	129.3	106	128.9	108	- 0.4
U.S.A. Illinois	100	125.1	71	125.9	29	+ 0.8
" Kentucky	124	123.6	72	123.4	52	- 0.2
" New Mexico	142	122.5	69	124.3	73	+ 1.8
" South Dakota	101	120.3	65	120.1	36	- 0.2
Summary						
female > male	11/20					
average difference						+ 0.8

Key Samples

Three samples provide an opportunity to examine more closely for gender differences: the England (Poundbury) sample by virtue of its size (n = 1271) and the two Thai samples due to the definite gender determination.

England (Poundbury)

The largest sample (Poundbury) has gender determined by established osteological assessments of the skeletons (Farewell and Molleson 1993: 168), and this sample likewise provides no evidence for a gender difference in NSA (Table 49).

Table 49

Mean male and female NSA and t-test results for the Poundbury sample

		NSA		*t-test*			
Sample	*n*	*male (n)*	*female (n)*	*t value*	*df*	*significance (2-tailed)*	*% of NSA explained by gender*
Poundbury	1271	125.4 (591)	125.5 (680)	-.333	1269	.739	0.01%

Thailand

The two Thai samples, as mentioned above, are unique here in being the only samples for which gender is certain. It is noteworthy that in both these samples, the mean female NSA is slightly lower than the mean male NSA (by 0.1° in the Bangkok sample, and by 0.4° in the Chiang Mai sample), although the differences are not statistically significant (Table 50).

Table 50

Mean male and female NSA and results of t-tests for the two Thai samples

		NSA		*t-test*			
Sample	*n*	*male (n)*	*female (n)*	*t value*	*df*	*significance (2-tailed)*	*% of NSA explained by gender*
Bangkok	137	126.4 (95)	126.3 (42)	.101	135	.920	0.01%
Chiang Mai	214	129.3 (106)	128.9 (108)	.566	212	.572	0.15%

Whether these small mean differences might be morphologically "real" is debatable, but this possibility should not be excluded considering that these samples alone derive from collections where gender is known. However, given the failure to replicate this finding using the many other samples with assigned (rather than known) gender, it is concluded that the overall findings of the present study suggest quite strongly that there is no consistent gender difference in the NSA.

Bilateral Asymmetry

Total Sample

The possibility of a bilateral difference in NSA can be examined first by using the complete (n = 8,271) femoral database, and the descriptive statistics for this total sample are shown in Table 51 and Figure 54.

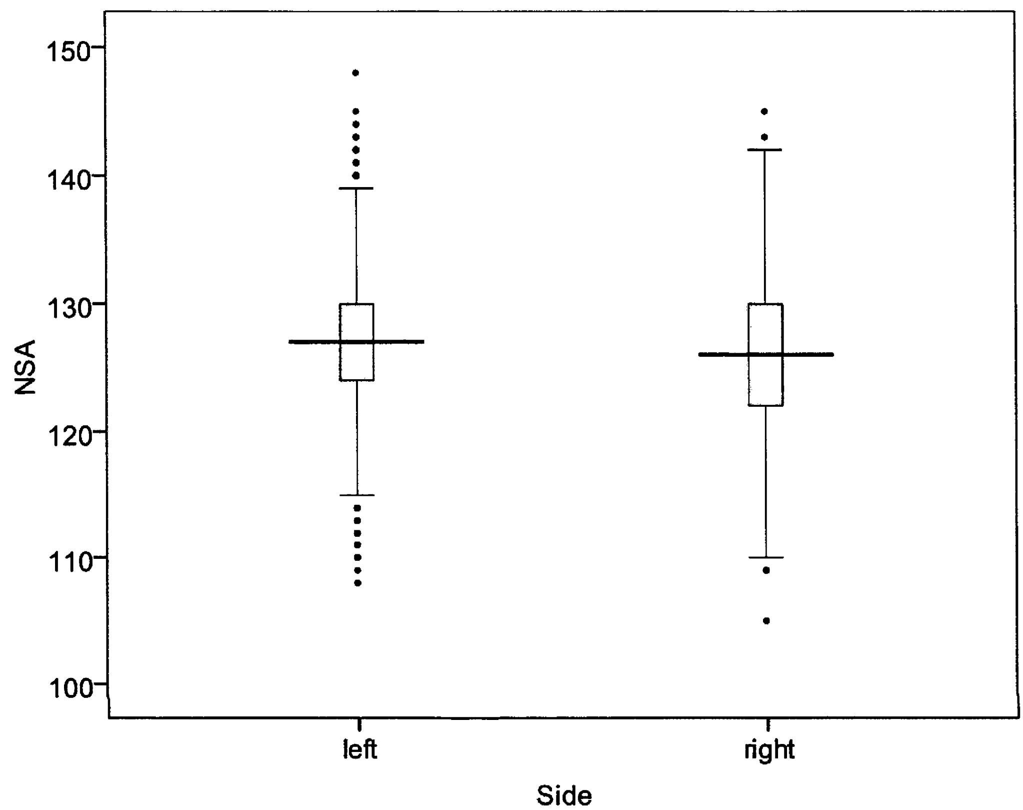
Table 51

Descriptive statistics for left and right NSA using the total sample

	Left	*Right*	
n	4141	4130	
total *n*			8271
% of total	50.07%	49.93%	100
mean NSA	127.02	125.71	
difference			1.31
median	127	126	
minimum	108	105	
maximum	148	145	
range	40	40	
standard deviation	5.356	5.693	
standard error of mean	.083	.089	
95% confidence interval for mean (lower bound)	126.86	125.53	
95% confidence interval for mean (upper bound)	127.18	125.88	
t-test (df 8236):			
significance (2-tailed, ** p <.001)			<.001**
% of NSA variance explained by asymmetry			1.396%

Figure 54

Distributions of left and right NSA using the total sample



In contrast to the conclusions regarding gender, these findings show a modest (1.3°) but statistically significant side difference in the NSA at a population level. Given that this finding is unexpected, it warrants close examination in an effort to decide whether or not it may be morphologically as well as statistically significant. As for gender differences, one method for exploring the side difference is to examine the side differences in the group samples.

62 Group Samples

To reduce unreliability associated with small sample sizes, only groups with $n \geq 5$ for both left and right femora are included; the results are shown in Table 52.

Table 52

Side differences for groups with $n \geq 5$ for both left and right NSA

Country / group	*n*	Left		Right		Difference (right - left)
		NSA	*n*	NSA	*n*	
AFRICA						
Algeria	53	123.5	26	123.3	27	- 0.24
Angola	11	128.7	6	128.8	5	+ 0.13
Bushmen	35	127.3	19	125.9	16	- 1.44
Canary Islands	223	125.6	108	125.7	115	+ 0.12
Egypt	136	128.0	73	125.8	63	- 2.17
Gabon	25	132.4	11	128.1	14	- 4.22
Khoikhoi	22	132.7	11	132.0	11	- 0.73
Madagascar	62	126.5	30	125.8	32	- 0.78
Mali	53	130.6	27	131.0	26	+ 0.45
Morocco	59	119.3	27	120.6	32	+ 1.30
Mozambique	10	121.4	5	120.2	5	- 1.20
Niger	43	130.5	18	128.0	25	- 2.54
Pygmy	16	132.0	8	131.1	8	- 0.88
Somalia	47	125.8	24	125.2	23	- 0.57
South Africa (Bantu)	10	124.2	5	123.0	5	- 1.20
Sudan (Nubian)	130	131.5	61	129.6	69	- 1.90
Tanzania	161	128.8	80	126.8	81	- 2.02
ASIA						
Ainu	233	125.8	118	124.8	115	- 1.01
Andaman Islands	81	137.1	41	135.0	40	- 2.08
China	115	128.8	57	125.5	58	- 3.36
India	47	130.9	23	128.9	24	- 1.95
Indonesia	11	131.3	6	131.8	5	+ 0.47
Japan (Edo period)	251	127.0	122	127.3	129	+ 0.33
Negrito	37	131.7	18	130.1	19	- 1.61
Nicobar Islands	12	132.0	6	131.2	6	- 0.83
Okhotsk	19	126.4	9	123.3	10	- 3.14

Philippines	92	130.5	39	127.1	53	- 3.36
Siberia	18	130.8	10	129.0	8	- 1.80
Sri Lanka	16	130.1	8	129.3	8	- 0.87
Thailand	457	127.4	232	127.6	225	+ 0.24
Veddah	16	133.1	8	131.4	8	- 1.74
Vietnam	16	127.1	8	125.5	8	- 1.63
AUSTRALIA						
Aboriginal (Roonka)	47	130.0	24	130.3	23	+ 0.26
EUROPE						
Czech Republic	56	129.4	21	125.3	35	- 4.07
England	1271	125.5	637	125.5	634	- 0.01
France	768	126.8	386	127.2	382	+ 0.34
Iceland	146	127.1	77	126.2	69	- 0.88
Russia	46	127.2	20	125.0	26	- 2.20
Sami	12	126.7	6	123.8	6	- 2.84
Scotland	434	128.1	226	127.3	208	- 0.81
Spain	14	125.7	7	122.7	7	- 3.00
NORTH AMERICA						
Canada	172	125.9	137	122.5	135	- 3.39
Dominican Republic	24	126.7	9	122.9	15	- 3.74
Greenland	90	129.2	46	129.5	44	+ 0.26
Inuit (Aleutian Is.)	324	121.7	164	118.8	160	- 2.87
Mexico	65	127.6	35	125.2	30	- 2.43
USA (excl. Alaska)	987	127.4	489	124.0	498	- 3.41
PACIFIC						
Easter Island	94	128.0	52	125.8	42	- 2.22
Hawaii	12	135.5	6	130.3	6	- 5.17
New Zealand – Maori	20	124.4	12	124.1	8	- 0.30
" Moriori	25	132.4	12	129.5	13	- 2.96
Papua New Guinea	59	132.5	30	131.6	29	- 0.95
Solomon Islands	20	133.4	10	131.3	10	- 2.10
Tahiti	11	133.8	6	130.8	5	- 3.03
Vanuatu	76	131.5	38	130.3	38	- 1.13
SOUTH AMERICA						
Argentina	108	130.5	55	127.3	53	- 3.24
Bolivia	33	118.1	21	116.5	12	- 1.60
Chile	49	125.9	26	122.9	23	- 3.05
Ecuador	193	127.0	93	124.9	100	- 2.14
Peru	211	124.0	102	120.6	109	- 3.41
Venezuela	68	127.7	37	126.1	31	- 1.67
Tierra del Fuego	34	122.9	17	121.8	17	- 1.06

Summary						
right > left	10/62					
average difference						- 1.65
" samples right > left	n = 10					+ 0.39
" samples left > right	n = 52					- 2.04

Again, in contrast to the findings for gender, the group NSA findings for bilateral asymmetry show a consistent side difference (left > right) for the great majority (52/62) groups. The average difference is 1.7° but, whereas the average side difference in groups where the right NSA exceeds the left is small (0.4°), the average side difference in groups where the left exceeds the right is 2°.

U.S.A. Samples

If the side difference is explored using one of the well-provenanced regional samples—the U.S.A., for instance—the findings provide quite compelling evidence for bilateral asymmetry (Table 53).

Table 53

Left-right side differences in NSA among the U.S.A. samples

State /sample	*n*	Left		Right		Difference (right - left)
		NSA	*n*	NSA	*n*	
USA (excluding Aleutian Is.)						
California / Chumash	78	125.9	41	126.8	37	+ 0.91
Florida / (various)	306	131.0	154	126.7	152	- 4.25
Illinois / Woodland	100	126.7	52	123.8	48	- 2.90
Kentucky / Archaic	129	125.6	65	121.7	64	- 3.89
Louisiana / Mississippian	118	128.8	52	124.8	66	- 4.01

New Mexico / Hawikuh	142	125.2	70	121.7	72	- 3.52
New York / Manhattan Is.	13	126.9	7	123.5	6	- 3.36
South Dakota / Arikara	101	121.7	48	118.9	53	- 2.84
Summary						
right > left	1 / 8					
average diff. (sample means)						- 2.98

This side difference of 3° among the mainland U.S.A. groups (the Inuit sample from the Aleutian Islands shows a similar side difference of 2.9°), together with the evidence for a reasonably consistent side difference of approximately 1-2° in the total femoral sample, suggests quite strongly that this bilateral asymmetry in the NSA is morphologically "real".

The question arises as to possible reasons for this asymmetry. The most likely candidate is leg dominance: a side difference in limb preference is well-documented not only in modern humans but many animal species, with the right leg dominant in most modern-day humans studied (e.g., Lenoir *et al.* 2006). This right-sided leg dominance would place greater biomechanical stresses on the right femoral neck during childhood development (when the NSA reduces markedly due to bio-mechanical loading), hence explaining the slightly lower right mean NSA. It could also be accentuated by any activity effect on the NSA, with higher habitual activity levels placing greater loads on the right — in most cases, dominant — femur.

Age Effect

Three samples provide data on age: the two Thai samples (where the age at death is known) and the Poundbury sample, in which age at death was estimated using a combination of skeletal indices (Farewell and Molleson 1993: 207-210). The mean age and the correlations with NSA for these samples are given in Table 55; none of the correlations are statistically significant.

Table 55

Mean age and correlations between age and NSA for the Thai and Poundbury samples

Sample	*n*	*Mean age (years)*	*Correlation with NSA (r)*
Bangkok	137	48.5	-.190
Chiang Mai	214	60.7	-.246
Poundbury	1271	39.4	-.156

Each of these samples can be examined for age trends individually.

Bangkok Sample

The age distribution for the Bangkok sample is shown in Figure 55, and the age distributions of the NSA (in five-year increments) are shown in Figure 56. The NSA distributions in the Bangkok sample show multiple fluctuations, with perhaps a slight overall trend towards a lower NSA with increasing age after 45 years.

Figure 55

Age distribution of the Bangkok sample

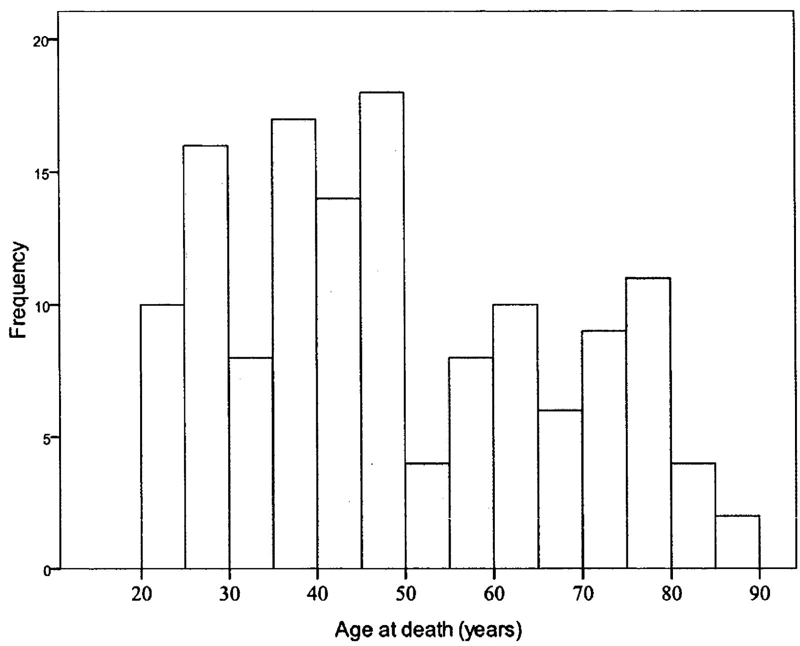
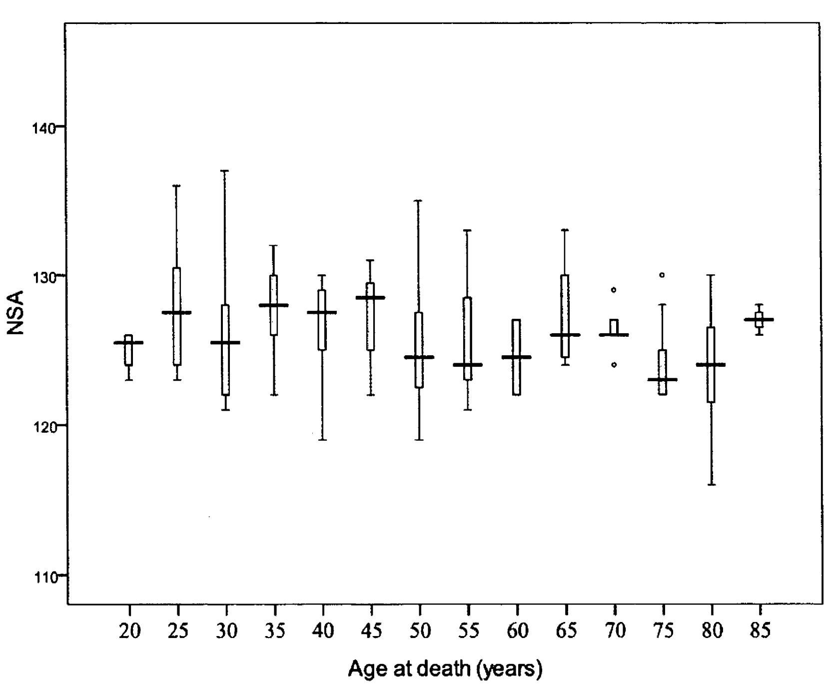


Figure 56

Age distribution of NSA for the Bangkok sample

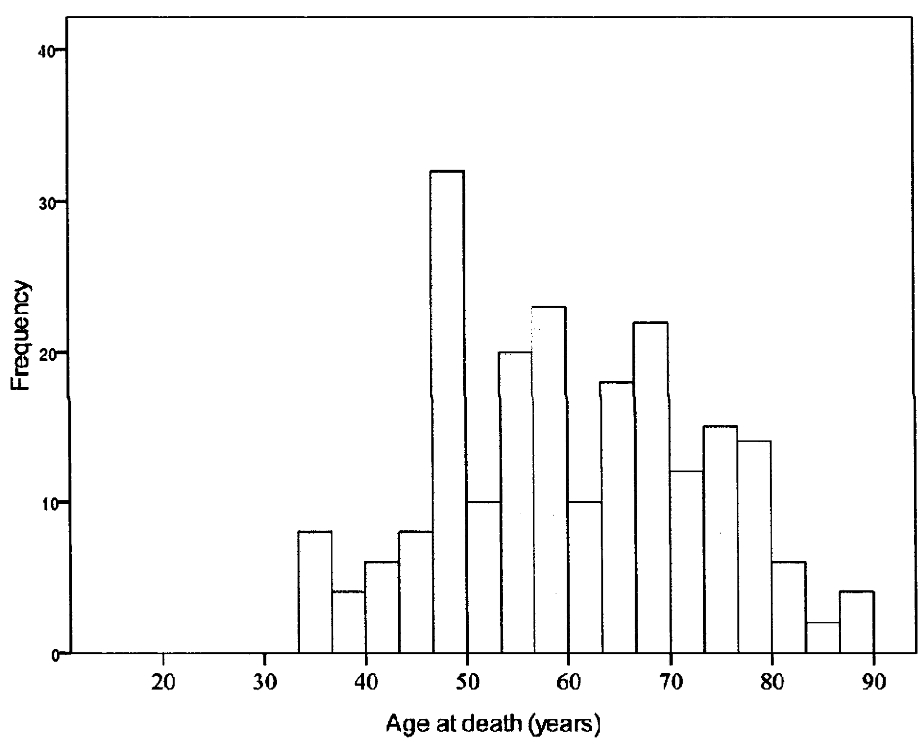


Chiang Mai Sample

The Chiang Mai sample has a more mature age distribution than Bangkok (Figure 57); the age distributions of the NSA are shown in Figure 58.

Figure 57

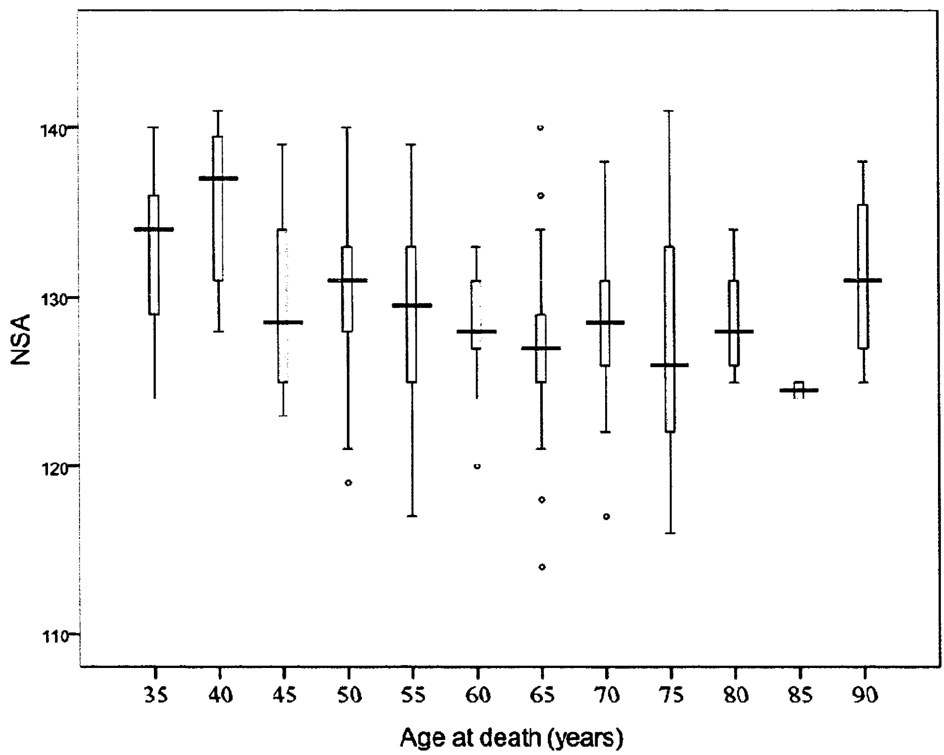
Age distribution of the Chiang Mai sample



As with the Bangkok sample, the Chiang Mai sample shows a trend towards a slight decline in NSA from age 45 years, but again the trend demonstrates considerable fluctuation.

Figure 58

Age distribution of NSA for the Chiang Mai sample



Poundbury Sample

The Poundbury sample has a younger age distribution (using the estimated skeletal age data) than the Thai samples (Figure 59); the age distributions of NSA are shown in Figure 60. As for the Thai samples, the Poundbury sample provides some evidence for a decline in NSA from 45 years, although this is offset by a marked increase after age 70 years.

Figure 59

Age distribution of the Poundbury sample

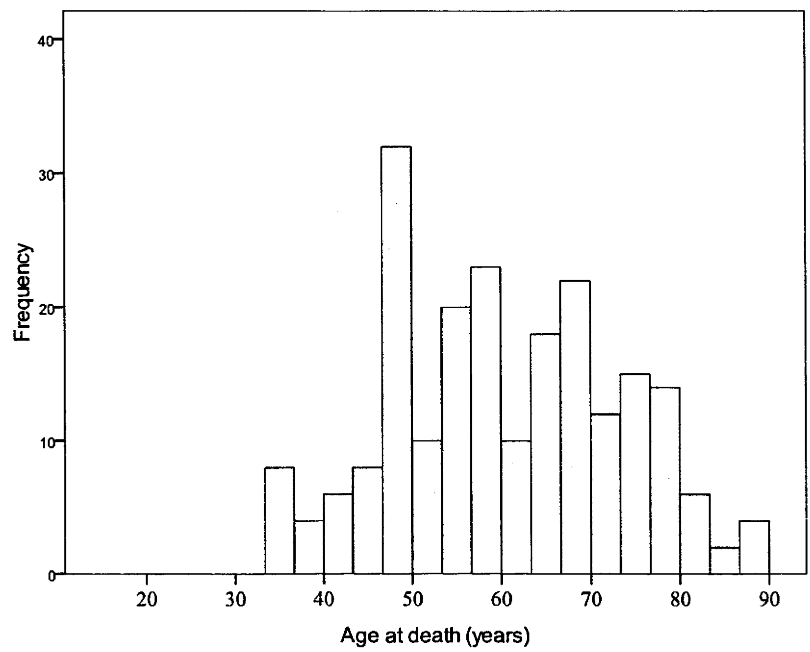
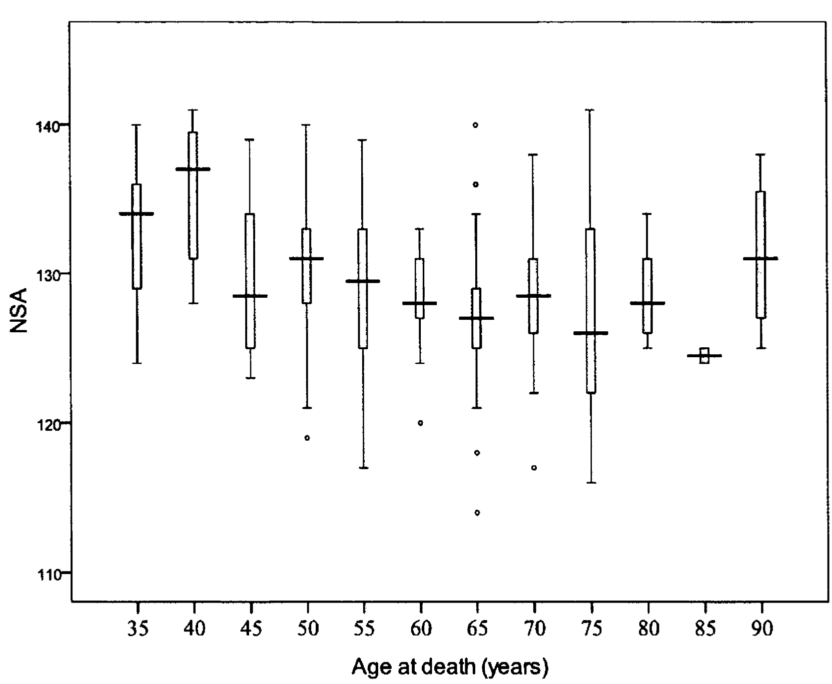


Figure 60

Age distribution of NSA for the Poundbury sample



Combined Age Samples

When all three samples with age data are combined, however, the evidence for a slight decline in NSA with advanced age is less convincing (Table 55 and Figure 61).

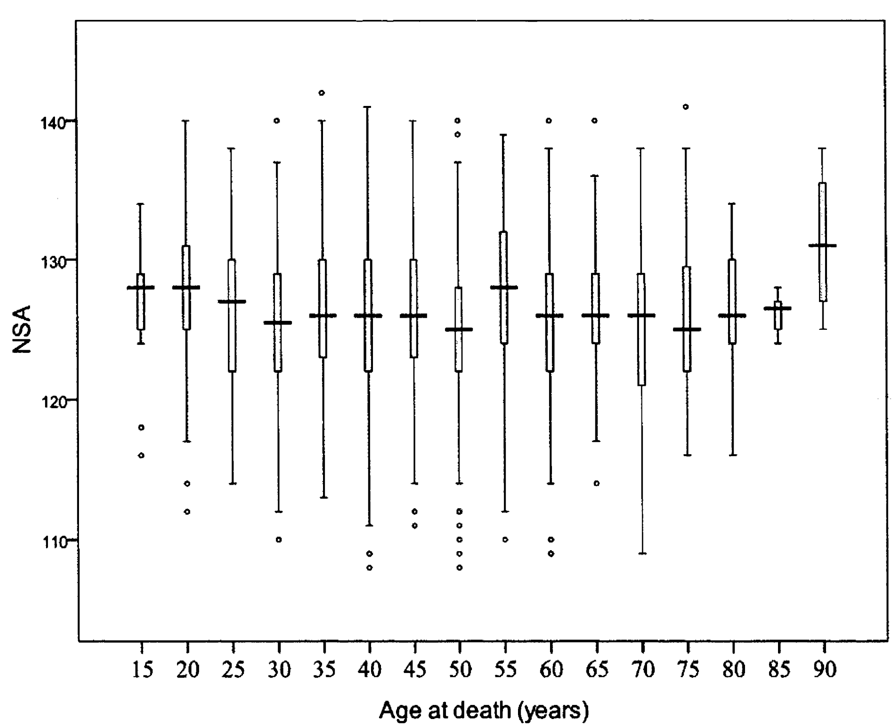
Table 55

Mean age and correlations between NSA and age for the combined samples

Sample	*n*	*Mean age (years)*	*Correlation with NSA (r)*
Combined	1622	43.0	-.044

Figure 61

Age distributions of NSA for the combined samples



Thai Sample

When the two Thai samples (Bangkok and Chiang Mai) are combined, there is an overall trend towards lower NSA after age 50, but the correlation between age and NSA is very low and not statistically significant (Table 56 and Figure 62).

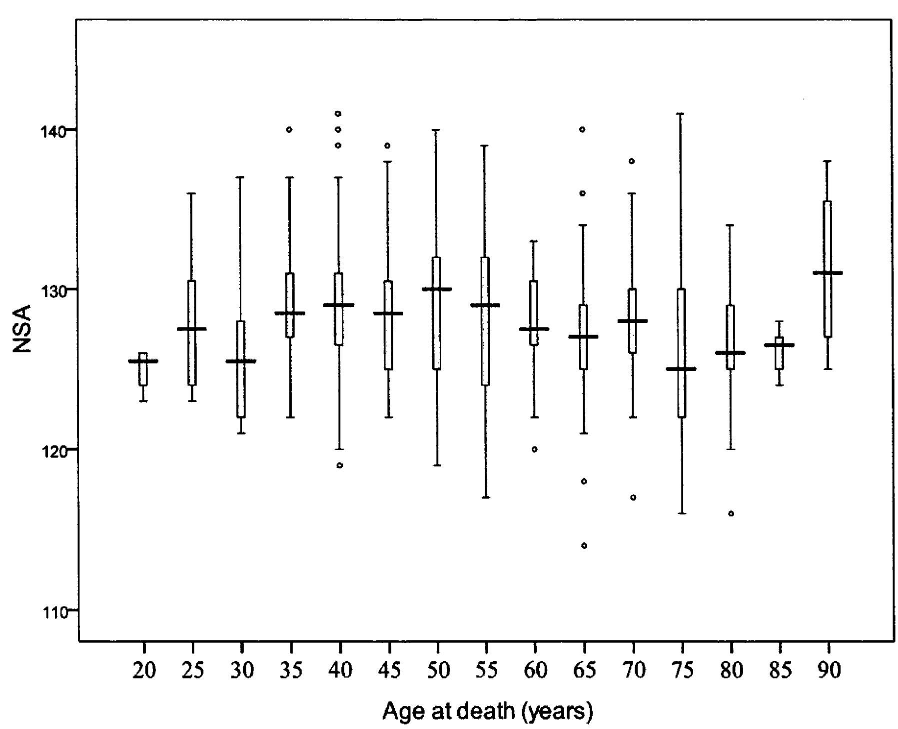
Table 56

Mean age and correlations between NSA and age for the combined Thai sample

Sample	*n*	*Mean age (years)*	*Correlation with NSA (r)*
Thailand	351	55.9	-.090

Figure 62

Age distributions of the NSA for the combined Thai sample



Since the two Thai samples alone have known age data, it may be concluded tentatively that there does indeed appear to be a modest trend towards lower NSA after middle age (45-50 years). However, an opposite trend in the Thai NSA samples after age 75 years (towards a higher NSA) suggests caution is advisable in drawing conclusions about a decline in NSA with advanced age based on these data.

Chapter 11: Additional Femoral Measures

Data on the seven additional femoral variables are presented in this chapter: femoral head diameter (FHD), maximum femoral length (MFL), bicondylar breadth (BCB) and the four shaft shape variables. Some but not all of these variables might be expected to vary in relation to climate, NSA, gender, lifestyle or side (left and right). In addition to being of some interest in their own right, the extent to which such expectations are corroborated may strengthen or weaken the inferences drawn earlier concerning the observed relationships between these factors and the NSA.

Femoral Head Diameter (FHD)

FHD is used widely as a skeletal correlate of body mass and gender (e.g., Auerbach and Ruff 2004, Stock and Pfeiffer 2004), and is analyzed here in relation to gender, climate and the NSA. As a skeletal correlate of body mass, for instance, FHD should manifest an association with climatic variables based on Bergmann's Rule, increasing in colder environments and possibly showing a corresponding correlation with NSA, given that the preceding analyses revealed significant climatic trends with the NSA. In the femoral database, 70 groups have FHD data, and the group FHD means (together with the assigned weather stations for the groups) are listed in Table 57.

Table 57

Mean male and female FHD and assigned weather stations for 70 groups

Country / group	NSA	Male		Female		Weather station
		n	FHD	*n*	FHD	
AFRICA						
Bushmen	126.7	9	40.0	19	37.1	Gaborone
Egypt	127.0			2	37.0	Cairo
Khoikhoi	129.7			6	38.0	Pretoria
Nigeria	129.5	2	43.2			Abuja
Pygmy	131.6	4	37.2	4	37.0	Kinshasa
Somalia	125.5	41	44.1	2	39.5	Mogadishu
Sudan (Nubian)	130.5	6	44.8			Khartoum
Tanzania	127.8	104	44.0	45	39.4	Dodoma
ASIA						
Ainu	125.3	50	45.0	29	40.2	Sapporo
Andaman Islands	136.1	26	38.1	14	35.4	Port Blair
China	127.2	108	45.1			Beijing
India	129.9	14	43.0	4	34.1	Delhi
Negrito	130.9	2	42.0	2	35.9	Manila
Nepal	128.0	2	47.5			Kathmandu
Sri Lanka	129.7	10	43.3	6	39.6	Colombo
Thailand						
" Bangkok	126.0	95	45.3	42	39.5	Bangkok
" Chiang Mai	129.2	106	44.5	107	40.0	Chiang Mai
Veddah	132.3	2	42.0	6	35.4	Colombo
AUSTRALIA						
South Australia	130.2	8	41.7	12	39.2	Adelaide
EUROPE						
England	125.5	507	47.5	553	41.9	London
France	127.0	10	44.8	11	40.3	Paris
Russia	126.0	2	48.0	2	37.4	Moscow
Sami	125.3	6	44.2	4	40.0	Helsinki
NORTH AMERICA						
Canada	124.2	54	43.2	16	39.9	Vancouver
Greenland	129.3	3	44.2	4	37.8	Nuuk
Guadeloupe	120.8	2	43.5	2	43.6	Basse-Terre
Inuit (Aleutian Is.)	120.2	177	46.1	111	41.6	Nikolski
USA (excl. Alaska)						
" Illinois	125.3	71	45.0	29	40.6	Carlinville

" Kentucky	123.6	64	43.2	50	39.1	Louisville
" New Mexico	123.4	60	43.2	70	37.7	Albuquerque
" South Dakota	120.2	58	47.6	35	41.9	Pierre
PACIFIC						
Easter Island	126.7	4	47.4	12	40.2	Hanga Roa
Guam	128.5			2	42.0	Hagatna
New Zealand						
" Maori	124.3	3	47.9			Wellington
" Moriori	130.9			3	40.3	Invercargill
PNG						
" New Britain	132.1	2	45.5			Rabaul
" (unspecified)	129.9	2	38.7			Port Moresby
Solomon Islands	132.4	6	40.5	4	40.3	Honiara
SOUTH AMERICA						
Bolivia	117.6			3	40.2	La Paz
Brazil	128.1	(1)	(47.0)			Brasilia
Chile	124.5	3	38.3	2	39.9	Santiago
Peru	122.2	46	43.9	40	38.7	Chimbote
Tierra del Fuego	122.4	(1)	(44.0)			Punta Arenas

FHD and Gender

Descriptive statistics and distributions of male and female FHD diameter are shown in Table 58 and Figure 63 respectively. The gender difference is statistically significant at the 0.001 level, with the male Pygmy FHD occupying an extreme low position, well below most female FHD group means. There is very little gender difference in the Pygmy FHD, although the sample size is small (n = 8). The low mean FHD of Pygmies reflects a comparatively low body mass which, as discussed earlier, is thermally adaptive in their hot, humid forested environments (Cavalli-Sforza 1986).

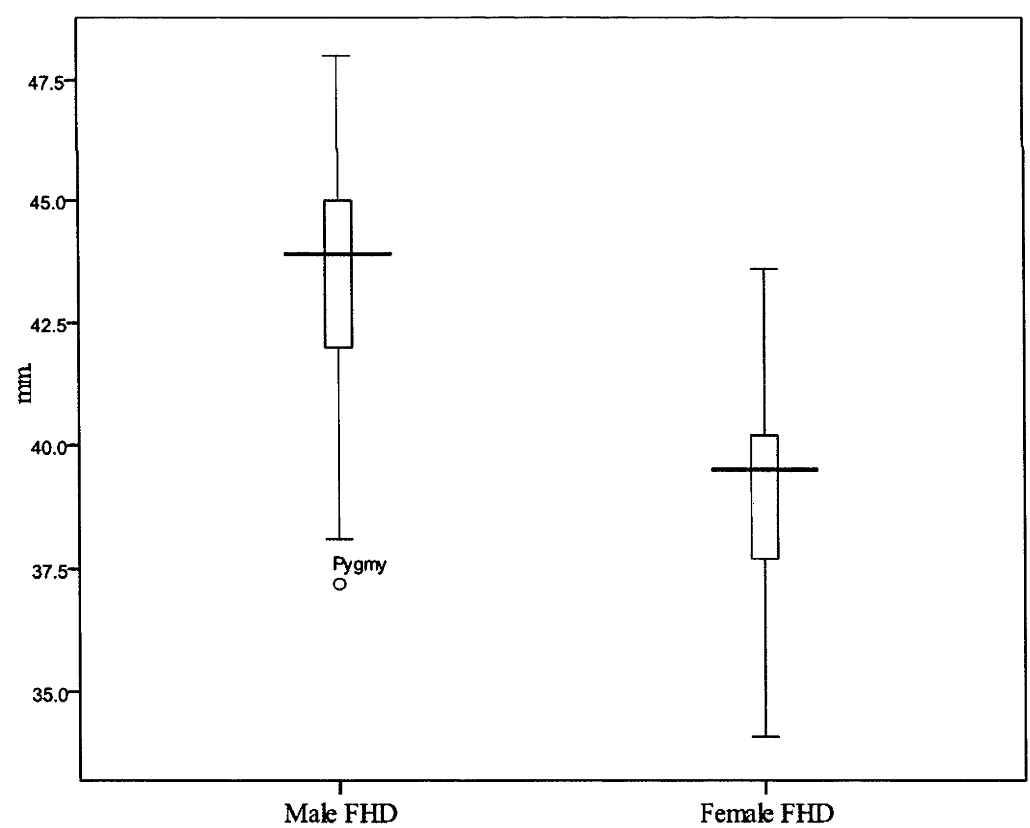
Table 58

Descriptive statistics for male and female FHD

Samples (group means)	*n*	*Minimum (mm.)*	*Maximum (mm.)*	*Mean (mm.)*	*SD*
Male FHD	36	37.2	48.0	43.7	2.82
Female FHD	34	34.1	43.6	39.1	2.12

Figure 63

Distributions of FHD for males and females



FHD and Climate

Using one-tailed tests and a Bonferroni-adjusted significance level of .006 (.05 ÷ (4 x 2) = .05 ÷ 8 = .00625), male FHD correlates significantly with latitude and both mean annual and mean winter temperature; female FHD shows weaker correlations with climate (Table 59). Reasons for weaker female FHD correlations are unclear; one may simply be the wide variations in FHD generally, apparent in the distributions of male FHD means and winter temperature (Figure 64). Nonetheless, the overall correlations between FHD (as a proxy for body mass) and climate are consistent with thermal expectations based on Bergmann's Rule, with a greater body mass associated with greater body heat production in colder environments.

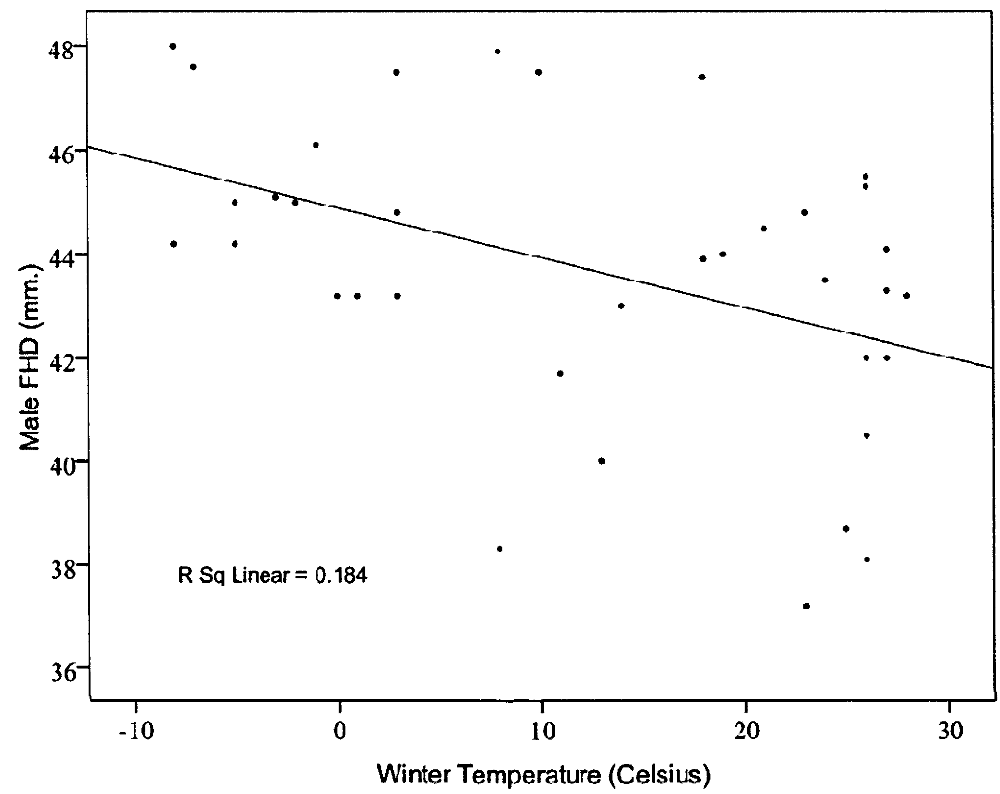
Table 59

Correlations and results of significance tests for FHD and the climatic indices

Climate Variable / Proxy	*Male FHD*		*Female FHD*	
	Correlation (r)	*Significance (* $p < .006$)*	*Correlation (r)*	*Significance (* $p < .006$)*
Latitude	+.446	.003*	+.204	.124
Annual mean temp. (°C)	-.426	.005*	-.275	.058
Summer mean temp. (°C)	-.338	.022	-.304	.040
Winter mean temp. (°C)	-.429	.005*	-.202	.126

Figure 64

Male FHD variation and winter temperature



FHD and NSA

Given the climatic correlations of both the NSA and FHD, these two femoral variables may be expected to show a correlation with each other. Statistically significant correlations (using one-tailed tests) are indeed found to exist for both male and female FHD and the NSA (Table 60 and Figure 65), providing corroborative support for the conclusions regarding the climatic trends in the NSA that emerged from the preceding analyses.

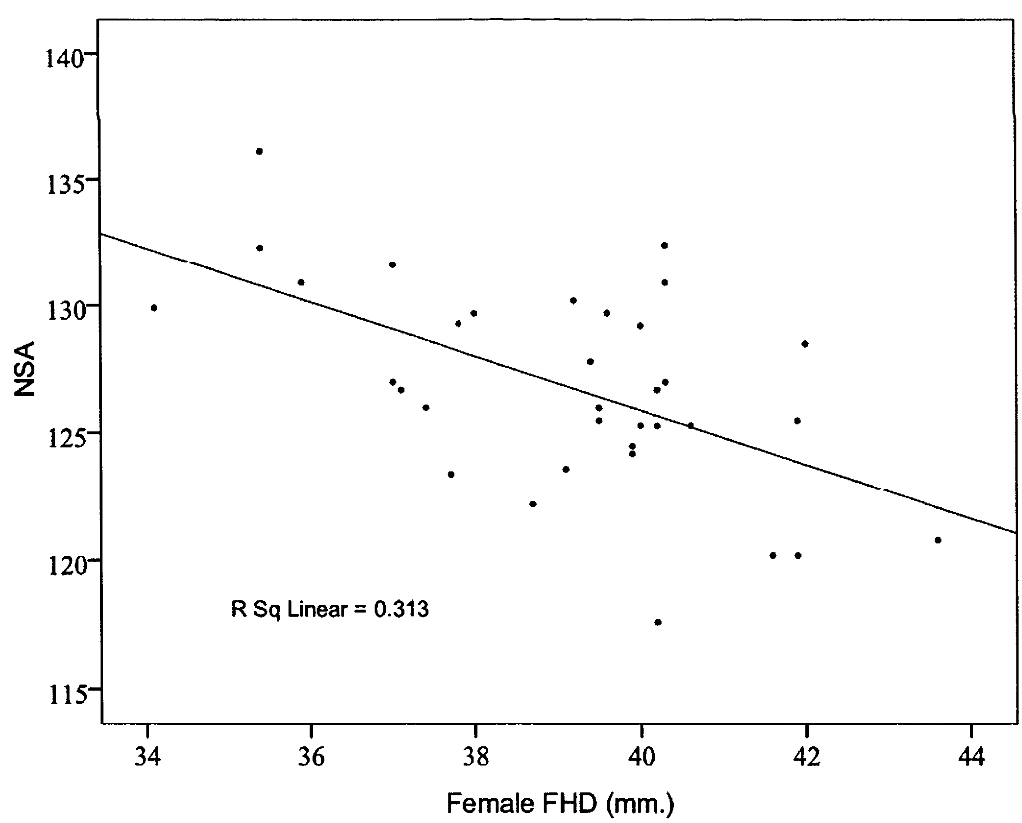
Table 60

Correlations and results of significance tests for FHD and NSA

Male FHD		*Female FHD*	
Correlation with NSA (r)	*Significance (** p < .005)*	*Correlation with NSA (r)*	*Significance (** p < .005)*
-.470*	.002**	-.560	<.001**

Figure 65

Scatterplot of female FHD and NSA



Maximum Femoral Length (MFL)

MFL is used widely as a skeletal correlate of stature and, to a lesser extent, gender (e.g., Kondo *et al.* 2000, Holliday 2002), but is not expected to show any correlation with climate based on Bergmann's or Allen's Rules (these relating to body mass and limb proportions, not absolute limb lengths). Neither would there be any grounds for anticipating a correlation between NSA and MFL, so MFL can serve here as a useful test of the climatic correlations for NSA. Neither is there much suggestion in the literature that bilateral asymmetry exists for MFL: limb length asymmetry is more marked in upper than lower limbs, and the small left-right differences in MFL observed in some groups generally show a left bias (Auerbach and Ruff 2006: 210). Yet the finding of bilateral asymmetry for the NSA here should lead to an equally unexpected finding for MFL, given that a lower right NSA should be associated with a slightly lower right MFL. The measures of NSA and MFL are independent, so MFL can serve additionally as a test for the unexpected asymmetry in the NSA.

43 sample groups have data on MFL: 41 have data on male MFL, and 32 have data on female MFL (Table 61). Three of the samples, however, comprise only a single femur: the Sudan female MFL, and the Bolivian and Fuegian male MFL's, and these are excluded from the analysis (these samples are bracketed in Table 61).

Table 61

Group means for NSA and male and female MFL, and the assigned weather stations

Country / group	NSA	Male		Female		Weather station
		n	MFL	*n*	MFL	
AFRICA						
Bushmen	126.7	8	416.1	19	396.8	Gaborone
Khoikhoi	129.7			4	405.3	Pretoria
Nigeria	129.5	2	428.5			Abuja
Pygmy	131.6	4	409.5	4	347.3	Kinshasa
Somalia	125.5	40	468.4	2	436.5	Mogadishu
Sudan (Nubian)	130.5	2	452.0	(1)	429.0	Khartoum
Tanzania	127.8	110	456.0	45	416.1	Dodoma
ASIA						
Ainu	125.3	40	416.2	12	389.4	Sapporo
Andaman Islands	136.1	24	387.5	14	377.3	Port Blair
China	127.2	112	426.6			Beijing
India	129.9	12	442.5	4	362.0	Delhi
Negrito	130.9	2	400.0	2	360.5	Manila
Nepal	128.0	2	462.5			Kathmandu
Sri Lanka	129.7	10	439.1	6	400.2	Colombo
Thailand						
" Bangkok	126.0	95	436.7	42	400.3	Bangkok
" Chiang Mai	129.2	106	427.2	105	401.5	Chiang Mai
Veddah	132.3	2	428.0	6	397.3	Colombo
AUSTRALIA						
South Australia	130.2	9	437.0	8	421.0	Adelaide
EUROPE						
Czech Republic	126.8	8	447.1	4	425.0	Prague
England	125.5	354	451.0	355	411.6	London
France	127.0	11	434.2	12	410.7	Paris
Russia	126.0	2	408.0			Moscow
Sami	125.3	6	388.2	6	365.5	Helsinki
NORTH AMERICA						
Canada						
" British Columbia	124.6	40	414.4	16	401.0	Vancouver
" Ontario	126.6	2	481.0			Ottawa
Greenland	129.3	4	401.5	4	382.0	Nuuk
Inuit (Aleutian Is.)	120.2	173	419.9	103	384.8	Nikolski
USA (excl. Alaska)						
" Illinois	125.3	69	445.2	29	423.4	Carlinville

" Kentucky	123.6	49	438.6	40	408.3	Louisville
" New Mexico	123.4	57	431.5	65	395.2	Albuquerque
" South Dakota	120.2	54	451.7	29	419.5	Pierre
PACIFIC						
Easter Island	126.7	5	447.0	9	394.8	Hanga Roa
Guam	128.5			2	395.5	Hagatna
New Zealand						
" Maori	124.3	2	476.5			Wellington
" Moriori	130.9			2	412.0	Invercargill
PNG						
" New Britain	132.1	2	444.0			Rabaul
" (unspecified)	129.9	2	413.0			Port Moresby
Solomon Islands	132.4	6	444.7	4	420.0	Honiara
SOUTH AMERICA						
Bolivia	117.6	(1)	447.0	3	407.5	La Paz
Brazil	128.1	2	425.0			Brasilia
Chile	124.5	3	419.3	2	376.5	Santiago
Peru	122.2	46	407.1	42	376.8	Chimbote
Tierra del Fuego	122.4	(1)	407.0			Punta Arenas

MFL and Gender

Descriptive statistics and the distributions of male and female MFL are shown in Table 62 and Figure 66 respectively.

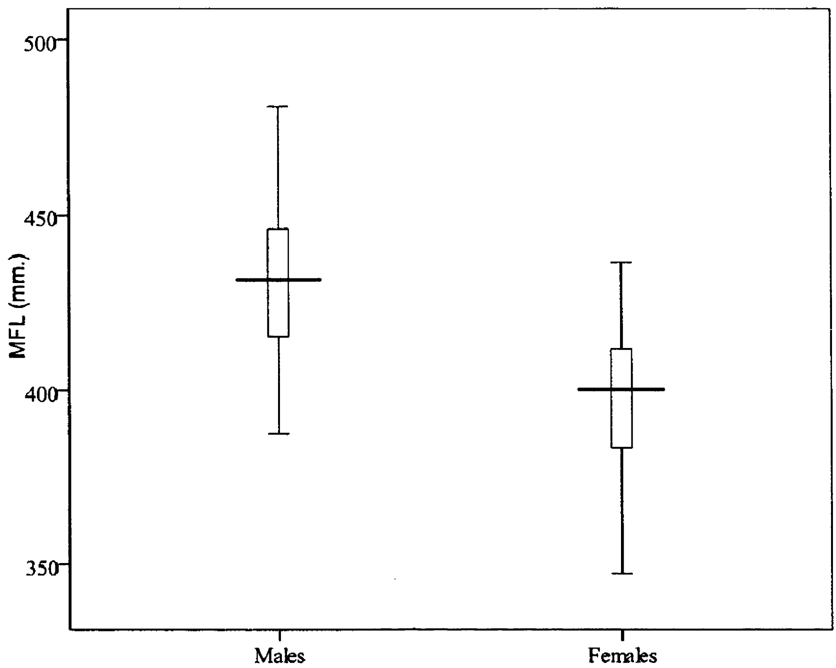
Table 62

Descriptive statistics for male and female MFL

Samples (group means)	*n*	*Minimum (mm.)*	*Maximum (mm.)*	*Mean (mm.)*	*SD*
Male MFL	39	387.5	481.0	431.5	22.6
Female MFL	31	347.3	436.5	397.2	21.3

Figure 66

Distributions of male and female MFL



As expected, the male MFL group means are significantly higher than the female group means; this gender difference in MFL is statistically significant at the $p < .001$ level.

MFL and Climate

When examined in relation to the climatic variables, neither the male nor the female mean MFL's show any substantial correlations with climate (Table 63 and Figure 67; adjusted significance level .006, 2-tailed tests). As mentioned above, insofar as the MFL constitutes a reliable skeletal correlate of stature, the observed lack of any correlation between MFL and climate is expected on thermal grounds.

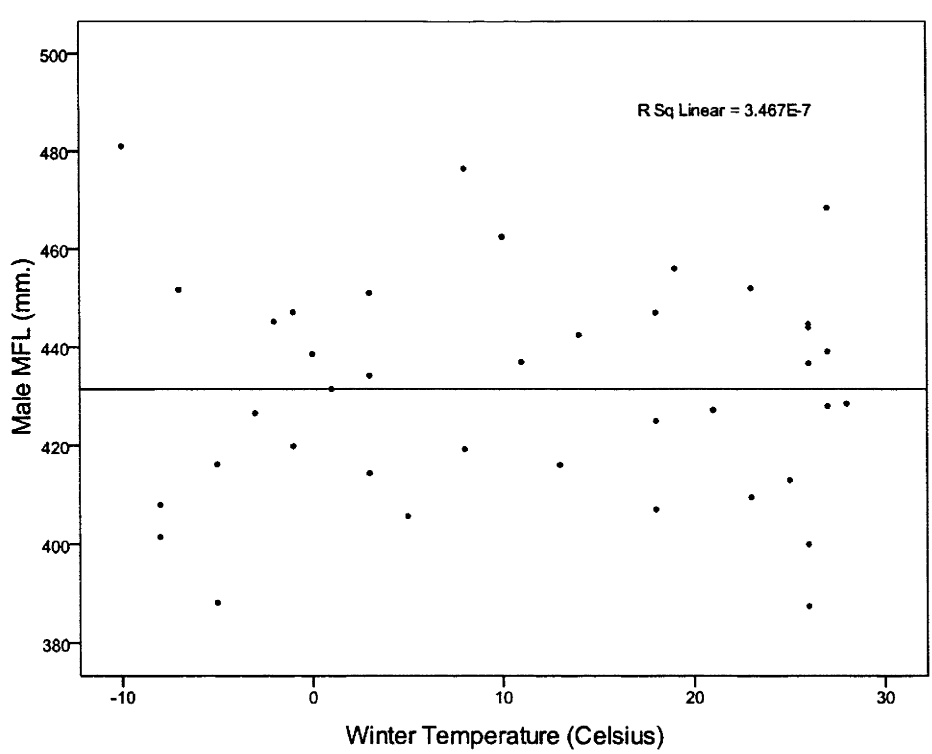
Table 63

Correlations between MFL and the climate variables

Climate Variable / Proxy	*Male MFL*		*Female MFL*	
	Correlation (r)	*Significance (* p < .006)*	*Correlation (r)*	*Significance (* p < .006)*
Latitude	-.048	.770	+.062	.741
Annual mean temp. (°C)	+.087	.600	-.108	.564
Summer mean temp. (C°)	+.211	.196	-.041	.829
Winter mean temp. (°C)	+.001	.997	-.109	.559

Figure 67

Distributions of male MFL and winter temperature



MFL and NSA

No correlations between the NSA and MFL are anticipated, and indeed none are found to occur (Table 64 and Figure 68).

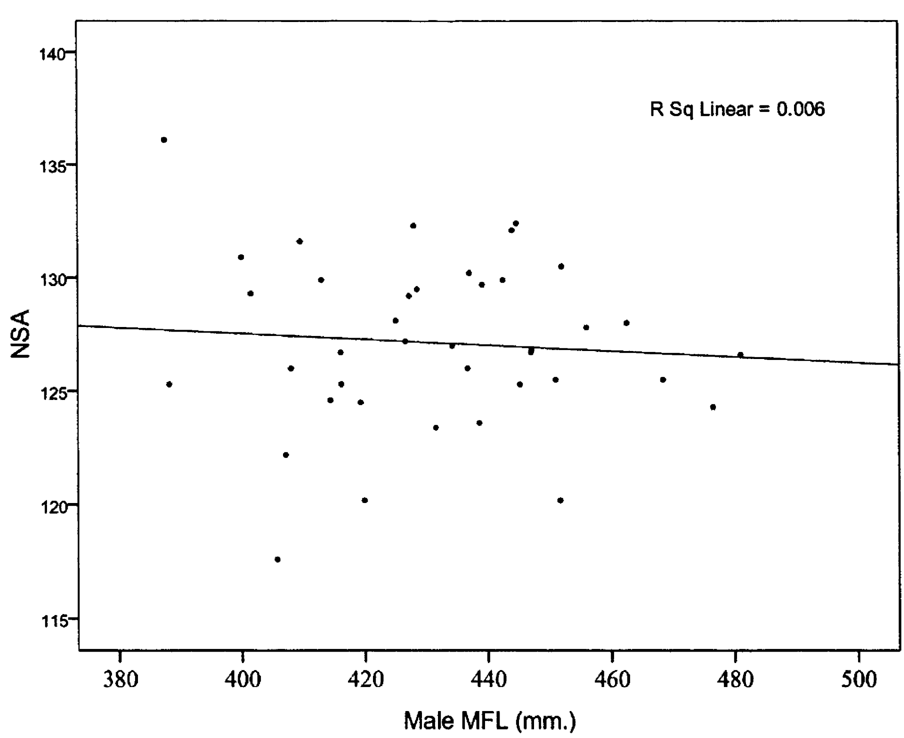
Table 64

Correlations between NSA and male and female MFL

Male MFL		*Female MFL*	
Correlation with NSA (r)	*Significance (* p < .01)*	*Correlation with NSA (r)*	*Significance (* p < .01)*
-.078	.638	-.173	.351

Figure 68

Distributions of male MFL in relation to NSA



MFL Bilateral Asymmetry

Descriptive statistics for left and right MFL, and t-test results, are shown in Table 65, and the distributions plotted in Figure 69.

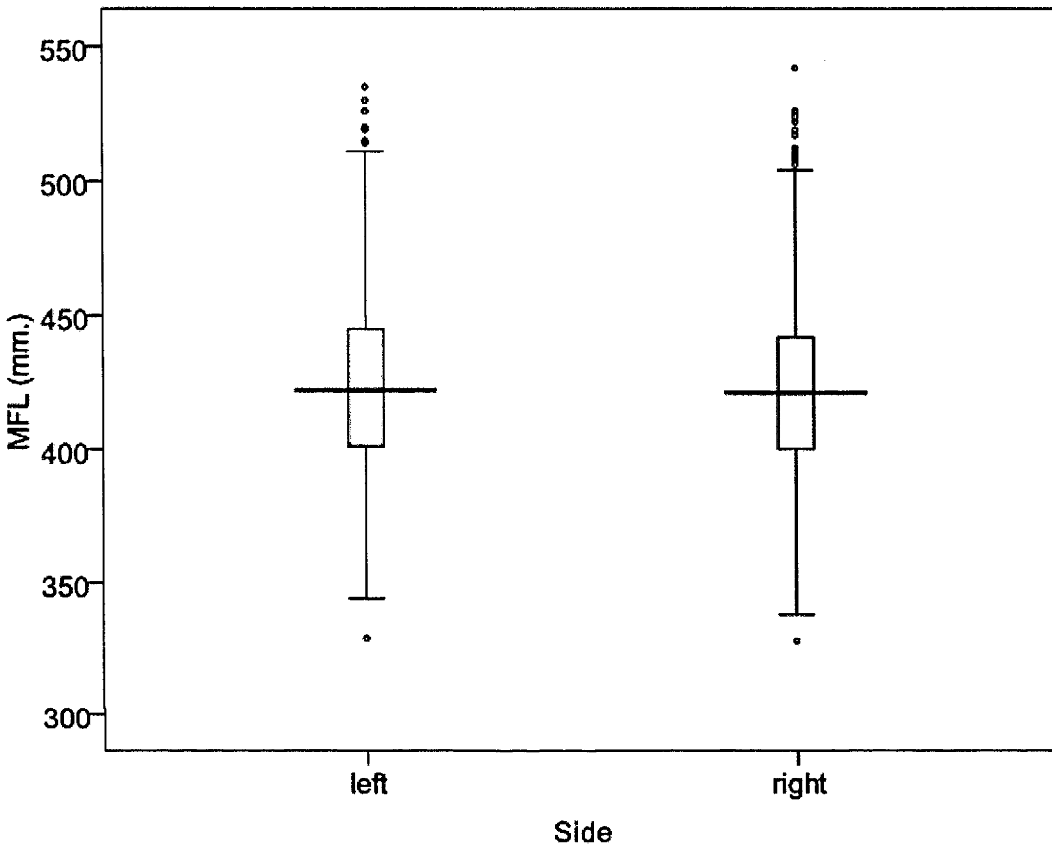
Table 65

Descriptive statistics and results of t-test for left and right MFL

	Left	*Right*	
n	2730	2763	
total *n*			5493
% of total	49.70%	50.30%	100
mean MFL	423.79	422.13	
difference			1.66
median	422	421	
minimum	329	328	
maximum	535	542	
range	206	214	
standard deviation	31.543	31.037	
standard error of mean	.604	.590	
95% confidence interval for mean (lower bound)	422.61	420.98	
95% confidence interval for mean (upper bound)	424.97	423.29	
t-test (df 5491):			
significance (2-tailed test, * $p \leq .05$)			.05*
% of MFL variance explained by asymmetry			0.070%

Figure 69

Distributions of left and right MFL



The results show a small difference between mean left and right MFL (1.66 mm.) which reaches statistical significance at the 0.05 level — t-test values $\leq .05$ are significant (Pallant 2001: 180). The slightly lower right MFL, if morphologically "real", is consistent with the bilateral asymmetry in NSA found in the preceding analyses, resulting from a lower right NSA. The anticipated magnitude of any effect of the slightly lower right NSA on the right MFL would be small, and would probably only become apparent with a very large sample size, as is the case here (n = 5,493). The question as to whether the observed bilateral MFL asymmetry in this analysis corresponds to a real difference at the population level or is merely an artifact of random variation in the large sample cannot be answered without more refined analyses, but one simple method is to compare the MFL results to those of other femoral variables with similarly large sample sizes. Both the FHD and BCB samples provide this opportunity, and the descriptive statistics for left and right FHD and BCB are shown in Table 66. Despite the large sample sizes, the bilateral differences are notably smaller and do not approach statistical significance.

Table 66

Bilateral asymmetry in FHD and BCB

	FHD	*BCB*
n (total; left, right)	6873; 3463, 3410	3995; 1997, 1998
mean / SD	43.37 / 3.97	76.03 / 6.35
left / right means	43.367 / 43.371	76.015 / 76.035
t-test df	6871	3993
significance (2-tailed tests)	.961	.920

Bicondylar Breadth (BCB)

To some extent, results for BCB may be expected to parallel those for FHD, insofar as the weight-bearing aspects of this index should similarly reflect variation in body mass (and hence lead to correlations with climate and NSA). 40 sample groups have data on BCB, although a few of the male and female BCB's must be excluded from analyses as they comprise only single femora—these are bracketed in Table 67.

Table 67

Male and female BCB group means, and assigned weather stations

Country / group	NSA	Male		Female		Weather station
		n	BCB	*n*	BCB	
AFRICA						
Bushmen	126.7	7	68.5	19	64.8	Gaborone
Khoikhoi	129.7			3	64.1	Pretoria
Nigeria	129.5	2	76.1			Abuja
Pygmy	131.6	4	64.0	2	57.9	Kinshasa
Somalia	125.5	33	78.2	(1)	71.7	Mogadishu
Sudan (Nubian)	130.5	(1)	74.3			Khartoum
Tanzania	127.8	97	77.8	38	68.3	Dodoma
ASIA						
Ainu	125.3	16	76.7	9	72.0	Sapporo
Andaman Islands	136.1	20	69.3	12	63.4	Port Blair
China	127.2	99	77.3			Beijing
India	129.9	10	77.0	4	64.9	Delhi
Negrito	130.9	2	72.2	2	66.5	Manila
Nepal	128.0	2	81.6			Kathmandu
Sri Lanka	129.7	9	75.4	6	70.7	Colombo
Thailand						
" Bangkok	126.0	94	80.2	41	70.2	Bangkok
" Chiang Mai	129.2	106	80.3	107	72.0	Chiang Mai
Veddah	132.3	2	77.5	4	61.1	Colombo
AUSTRALIA						
South Australia	130.2	4	75.0	4	67.8	Adelaide
EUROPE						
Czech Republic	126.8	7	81.9	(2)	(82.6)	Prague
England	125.5	253	82.1	237	73.5	London
France	127.0	6	77.2	7	72.6	Paris
Russia	126.0	2	80.2	2	69.1	Moscow
Sami	125.3	3	75.2	2	67.8	Helsinki
NORTH AMERICA						
Canada	124.2	25	77.0	9	72.6	Vancouver
Greenland	129.3	3	78.7	2	63.3	Nuuk
Inuit (Aleutian Is.)	120.2	134	81.3	79	73.4	Nikolski

USA (excl. Alaska)						
" Illinois	125.3	43	78.9	18	70.8	Carlinville
" Kentucky	123.6	35	76.7	22	69.8	Louisville
" New Mexico	123.4	50	78.0	58	68.9	Albuquerque
" South Dakota	120.2	44	82.7	25	75.7	Pierre
PACIFIC						
Easter Island	126.7	4	80.0	7	71.5	Hanga Roa
Guam	128.5					Hagatna
New Zealand						
" Maori	124.3	2	89.0			Wellington
" Moriori	130.9			2	71.7	Invercargill
PNG	129.9	2	68.5			Port Moresby
Solomon Islands	132.4	4	71.7	4	71.8	Honiara
SOUTH AMERICA						
Bolivia	117.6	(1)	83.6	2	70.7	La Paz
Chile	124.5	2	75.1	(1)	69.0	Santiago
Peru	122.2	34	76.5	27	68.9	Chimbote
Tierra del Fuego	122.4	(1)	79.5			Punta Arenas

BCB and Gender

Descriptive statistics and distributions for BCB and gender are shown in Table 68 and Figure 70 respectively.

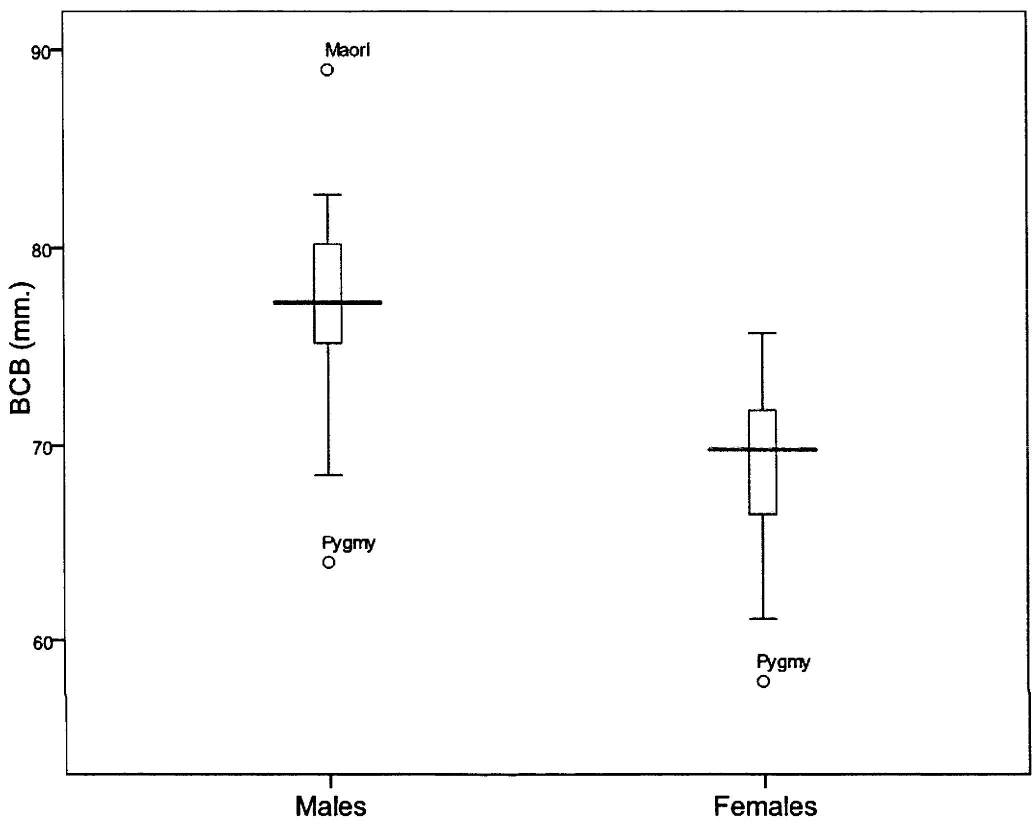
Table 68

Descriptive statistics for male and female BCB

Samples (group means)	*n*	*Minimum (mm.)*	*Maximum (mm.)*	*Mean (mm.)*	*SD*
Male BCB	34	64.0	89.0	77.0	4.78
Female BCB	30	57.9	82.6	69.3	4.77

Figure 70

Distributions of male and female BCB



These results parallel those for FHD, reflecting similar weight-bearing and body mass considerations: the male BCB is greater than the female BCB, and the difference is statistically significant at the 0.001 level. The more extreme group means are noteworthy: a high male Maori BCB (reflecting greater body mass associated with their geographical location in a relatively cool Polynesian environment), and low Pygmy BCB's for both the male and female Pygmy samples (reflecting low body mass in their hot, humid forested environments).

BCB and Climate

The correlations between male and female BCB and the climate variables, and results of significance tests (Bonferroni level 0.00625), are shown in Table 69, and the distributions of the male BCB group means in relation to latitude are plotted in Figure 71. Again, the results are not dissimilar to those for FHD: stronger (and more statistically significant) climate correlations for male BCB compared to female BCB, with the stronger correlations for winter than summer mean temperatures probably reflecting a stronger selection pressure of cold exposure compared to heat stress on body mass variation among modern humans.

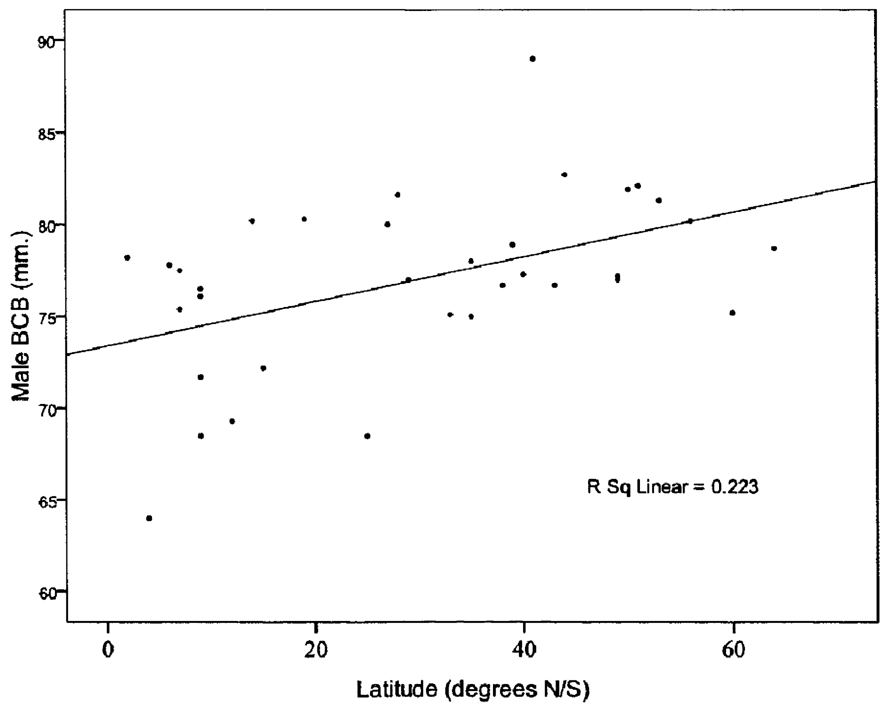
Table 69

Correlations between BCB and climate variables and results of significance tests

Climate Variable / Proxy	*Male BCB*		*Female BCB*	
	Correlation (r)	*Significance (* $p \leq .006$)*	*Correlation (r)*	*Significance (* $p \leq .006$)*
Latitude	+.472	.002*	+.371	.024
Annual mean temp. (°C)	-.466	.003*	-.377	.022
Summer mean temp. (°C)	-.410	.008	-.257	.089
Winter mean temp. (°C)	-.430	.006*	-.375	.022

Figure 71

Scatterplot of male BCB and latitude



BCB and NSA

Given the climatic patterning of NSA variation due to the thermal role of body shape, and the corresponding climatic variation in BCB due to the thermal role of body mass, correlations between NSA and BCB may be anticipated on thermal grounds. The correlations and results of significance tests for NSA and BCB (Table 70) bear out these expectations (Bonferroni level 0.025), illustrated in the scatterplot of NSA and female BCB (Figure 72).

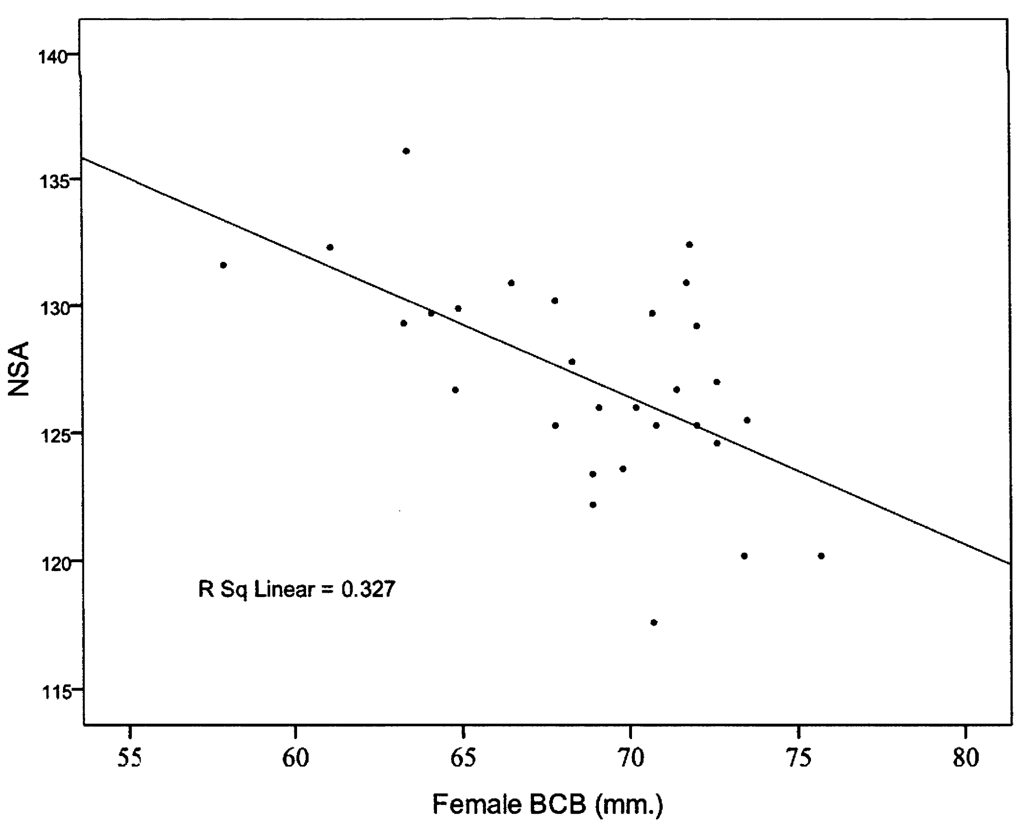
Table 70

Correlations between BCB and NSA and results of significance tests

Male BCB		*Female BCB*	
Correlation with NSA (r)	*Significance (** p < .0025)*	*Correlation with NSA (r)*	*Significance (** p < .0025)*
-.555	<.001**	-.572	.001**

Figure 72

Scatterplot of BCB and NSA

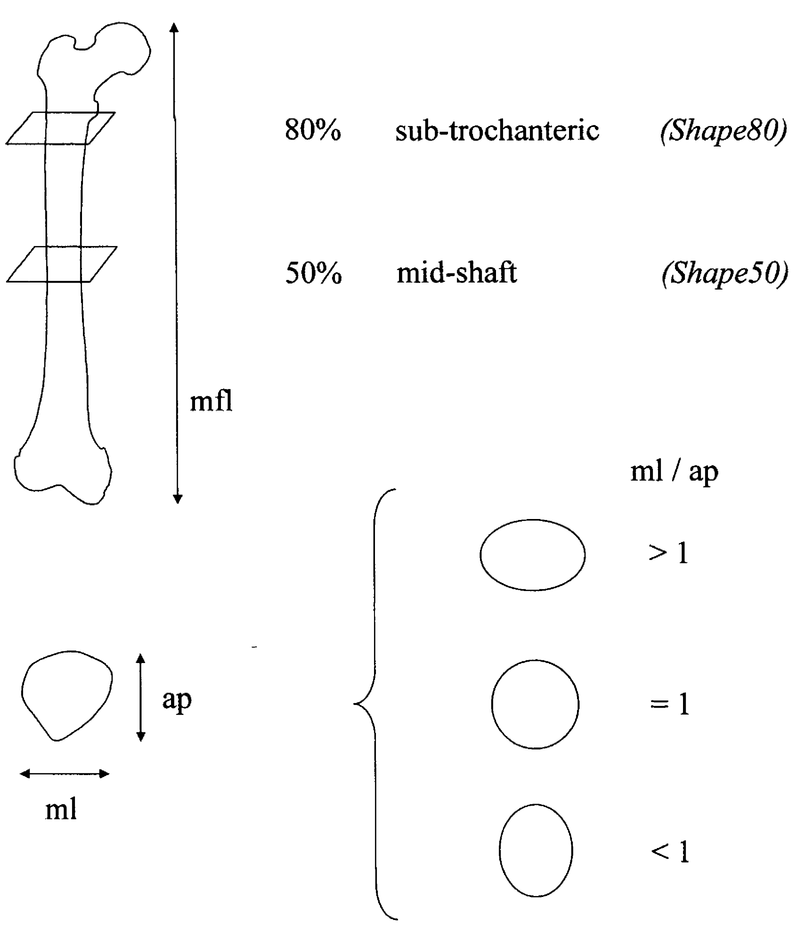


Shaft Shape

The four measured femoral shaft shape variables—AP80, ML80, AP50 and ML50—allow the calculation of two shaft variables reflecting the varying ratios of antero-posterior and medio-lateral diameters at the sub-trochanteric and mid-shaft levels (Figure 73). These variables are comparable (though not equivalent) to the femur-shaft index, which measures platymeria (Brothwell 1981, pp. 88-89).

Figure 73

Measured shaft variables and the two calculated shaft shape variables



Data on the measured shaft shape variables are provided by 71 groups; the mean Shape80 and Shape50 scores for these groups are listed in Table 71 and plotted in Figure 74.

Table 71

Groups means and SD for the two shaft shape variables

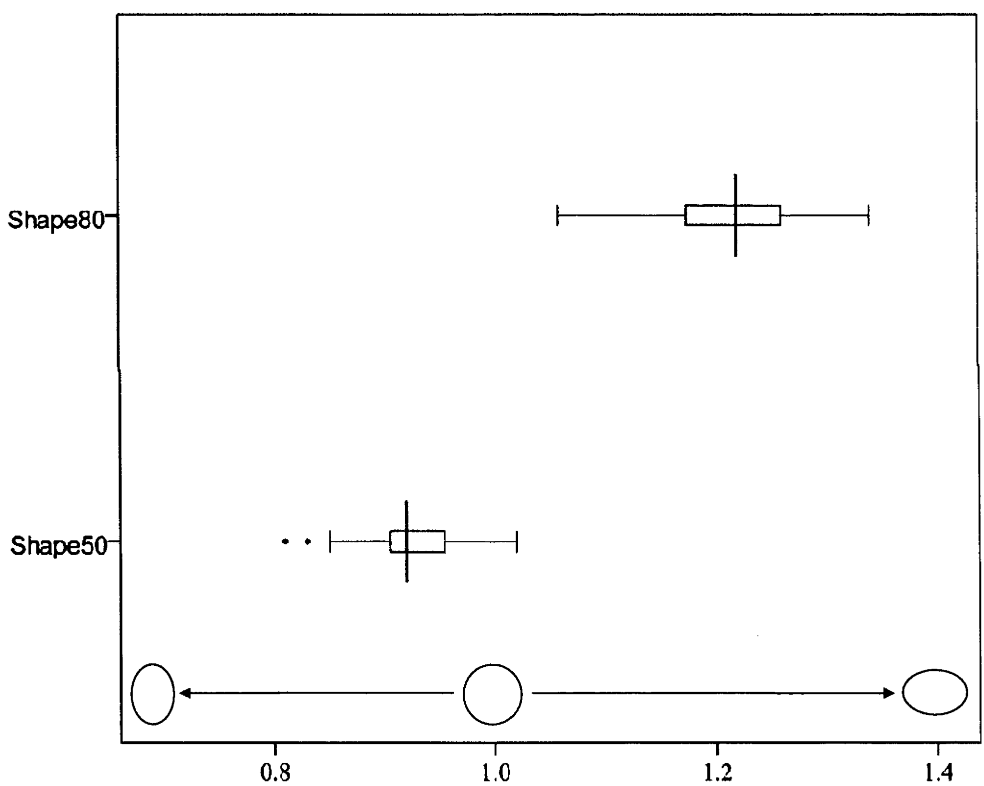
Groups		Shape80 *(sub-trochanteric)*		Shape50 *(mid-shaft)*	
	n	*mean*	*SD*	*mean*	*SD*
AFRICA					
Algeria (Berber)	16	1.26	0.13	0.96	0.13
Angola	11	1.25	0.09	0.93	0.06
Canary Islands	176	1.29	0.10	0.91	0.08
Egypt	65	1.19	0.11	0.93	0.83
Gabon	15	1.23	0.77	0.92	0.76
Madagascar	46	1.23	0.09	0.89	0.07
Mali	29	1.19	0.09	0.91	0.07
Morocco (Berber)	13	1.29	0.12	0.95	0.07
Niger	22	1.18	0.07	0.91	0.07
Somalia	43	1.27	0.13	0.97	0.14
South Africa (Khoikhoi)	18	1.21	0.11	0.96	0.10
South Africa (Bantu)	10	1.15	0.09	0.90	0.05
Sudan	51	1.19	0.10	0.88	0.08
Tanzania	155	1.22	0.10	0.88	0.08
ASIA					
China	112	1.15	0.08	0.93	0.08
India	35	1.22	0.12	0.93	0.13
Japan (Edo)	241	1.17	0.13	1.00	0.09
Nicobar Islands	11	1.28	0.07	0.93	0.07
Philippines	72	1.26	0.09	0.86	0.07
Siberia	15	1.34	0.14	0.93	0.07
Sri Lanka	16	1.21	0.11	1.01	0.07
Syria	12	1.23	0.07	0.98	0.06
Thailand (Bangkok)	243	1.14	0.10	0.92	0.08
Thailand (Chiang Mai)	213	1.10	0.10	0.92	0.08
AUSTRALIA					
South Australia (Roonka)	21	1.18	0.13	0.92	0.07

EUROPE					
Czech Republic	48	1.19	0.12	1.00	0.09
England	695	1.23	0.10	0.97	0.08
France (mesolithic)	11	1.29	0.07	0.94	0.06
France (neolithic)	207	1.31	0.10	0.94	0.07
France (provincial)	173	1.23	0.10	0.95	0.08
France (urban - Paris)	88	1.19	0.10	0.94	0.08
Iceland	107	1.17	0.13	0.96	0.07
Russia (neolithic)	25	1.32	0.09	1.00	0.09
Russia (urban - Moscow)	12	1.26	0.08	0.99	0.11
Scotland (Orkney Islands)	47	1.25	0.11	0.94	0.07
Scotland (Shetland Islands)	128	1.30	0.10	0.96	0.07
NORTH AMERICA					
Canada (British Columbia)	156	1.17	0.09	0.92	0.07
Dominican Republic	12	1.13	0.10	0.90	0.06
Greenland	47	1.22	0.10	0.88	0.08
Mexico (Valley of Mexico)	14	1.24	0.12	0.91	0.07
U.S.A. (California)	51	1.29	0.08	0.83	0.07
U.S.A. (Florida)	76	1.15	0.13	0.91	0.08
U.S.A. (Illinois)	98	1.07	0.14	0.92	0.09
U.S.A. (Kentucky)	93	1.06	0.11	0.90	0.08
U.S.A. (Louisiana)	75	1.06	0.11	0.92	0.08
U.S.A. (New Mexico)	122	1.06	0.11	0.92	0.08
U.S.A. (New York)	11	1.14	0.08	0.89	0.08
U.S.A. (South Dakota)	82	1.06	0.13	0.91	0.07
PACIFIC					
Easter Island	74	1.23	0.12	0.89	0.07
New Zealand (Moriori)	23	1.31	0.16	0.92	0.08
PNG (Sawatty Island)	14	1.30	0.08	0.91	0.09
PNG (New Britain)	24	1.19	0.10	0.83	0.04
Solomon Islands	13	1.06	0.13	0.81	0.05
Vanuatu	22	1.25	0.09	0.86	0.08
SOUTH AMERICA					
Argentina	87	1.26	0.11	0.92	0.10
Bolivia	14	1.31	0.12	1.02	0.09
Chile	39	1.26	0.11	0.94	0.09
Ecuador	92	1.30	0.08	0.92	0.06
Peru (Wari empire)	89	1.29	0.10	0.97	0.09
Peru (Chicama)	86	1.19	0.11	1.02	0.09
Venezuela	34	1.24	0.09	0.97	0.08
OTHER GROUPS					
Ainu	121	1.19	0.11	0.96	0.09
Andaman Islands	78	1.20	0.10	0.89	0.06
Bushmen	33	1.21	0.11	0.89	0.11
Fuegian (total)	15	1.25	0.14	0.92	0.07

Inuit (Aleutian Islands)	274	1.29	0.10	0.95	0.07
Negrito	32	1.20	0.09	0.85	0.07
Okhotsk	11	1.25	0.14	0.97	0.07
Pygmy	15	1.14	0.10	0.88	0.05
Sami (Lapps)	12	1.13	0.09	0.92	0.05
Veddah	14	1.23	0.07	0.93	0.07

Figure 74

Distributions of the two shaft shape variables



In Figure 74, the distributions for Shape80 show a medio-laterally broader cross-sectional shape of the femoral shaft towards the proximal epiphysis (relating to greater medio-lateral biomechanical loadings associated with proximity to the broad pelvis), whereas Shape50 shows the more elongated shape (antero-posteriorly) of the femoral shaft at the mid-shaft level (reflecting the relatively stronger antero-posterior loadings associated with muscle activity and locomotion at more distal levels of the femoral shaft). The correlations between the two calculated shaft shape variables and the other femoral variables (and the results of significance tests) are listed in Table 72. Only one correlation is statistically significant at the 0.004 level (two-tailed tests, Bonferroni correction 0.05 ÷ (7 x 2) = 0.05 ÷ 14 = .0036) — Shape50 and NSA; the scatterplot of Shape50 and NSA is shown in Figure 75.

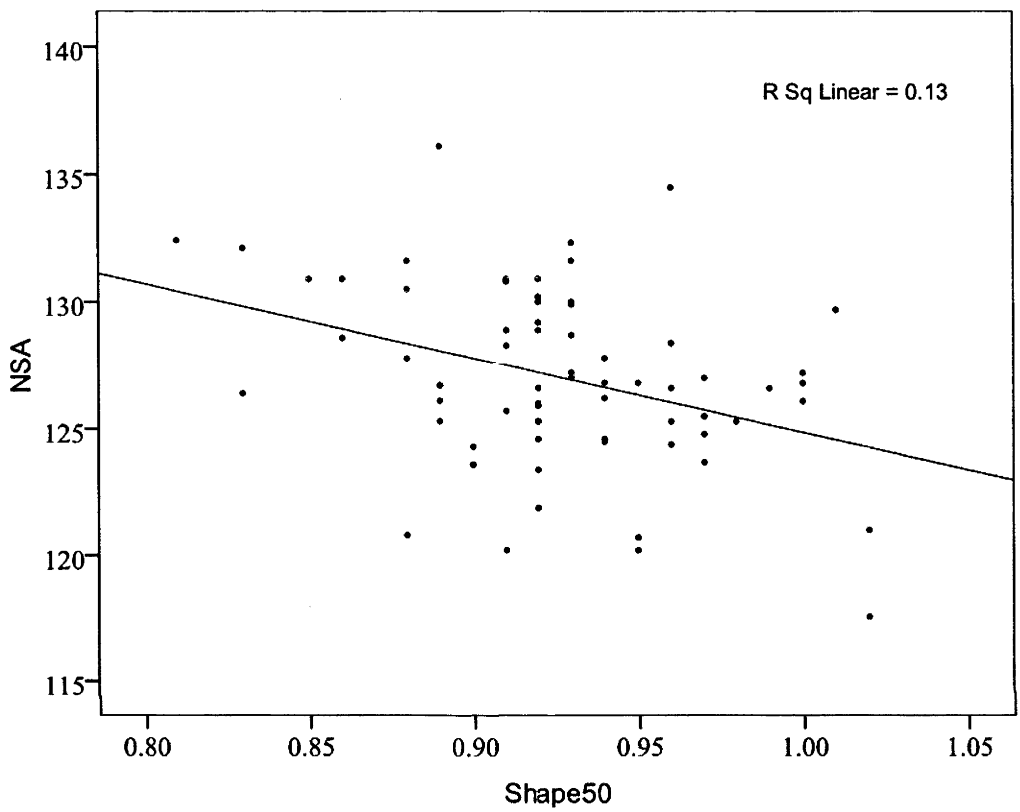
Table 72

Correlations between the shaft shape and other femoral variables, and results of significance tests

		Shape80		*Shape50*	
Femoral variables	*n*	*Correlation (r)*	*Significance (* p < .004, 2-tailed)*	*Correlation (r)*	*Significance (* p < .004, 2-tailed)*
NSA	71	-.010	.935	-.361	.002*
FHD (males)	31	+.047	.803	+.302	.099
FHD (females)	32	-.090	.623	+.189	.299
MFL (males)	32	-.089	.630	+.016	.930
MFL (females)	32	-.079	.667	+.123	.503
BCB (males)	30	+.068	.722	+.451	.012
BCB (females)	30	-.081	.672	+.248	.187

Figure 75

Scatterplot of Shape50 and NSA



The poor correlations between shaft shape and the other measured femoral variables are not unexpected, as there are no compelling thermal or other bio-mechanical reasons to anticipate correlations. Lifestyle factors such as varying activity levels and patterns associated with different economic and mobility categ-ories have been implicated in the literature as exerting an influence on variation in the femoral shaft, rather than climate or other thermal factors.

Generally weak correlations are found between the shaft shape and climate variables (Table 73). With two-tailed tests and a Bonferroni correction yielding a significance level of .006 (0.05 ÷ (4 x 2) = 0.05 ÷ 8 = .00625), the three that reach statistical significance appear anomalous in this regard. A negative association between hotter summers and Shape80 may suggest a narrowing of the pelvis (and hence less medio-lateral loading on the proximal femoral shaft) in relation to heat stress, and similar considerations might contribute to the observed correlations between higher temperatures and a narrowing at the mid-shaft level, which could be associated with a more linear body build in warmer climates (Figure 76).

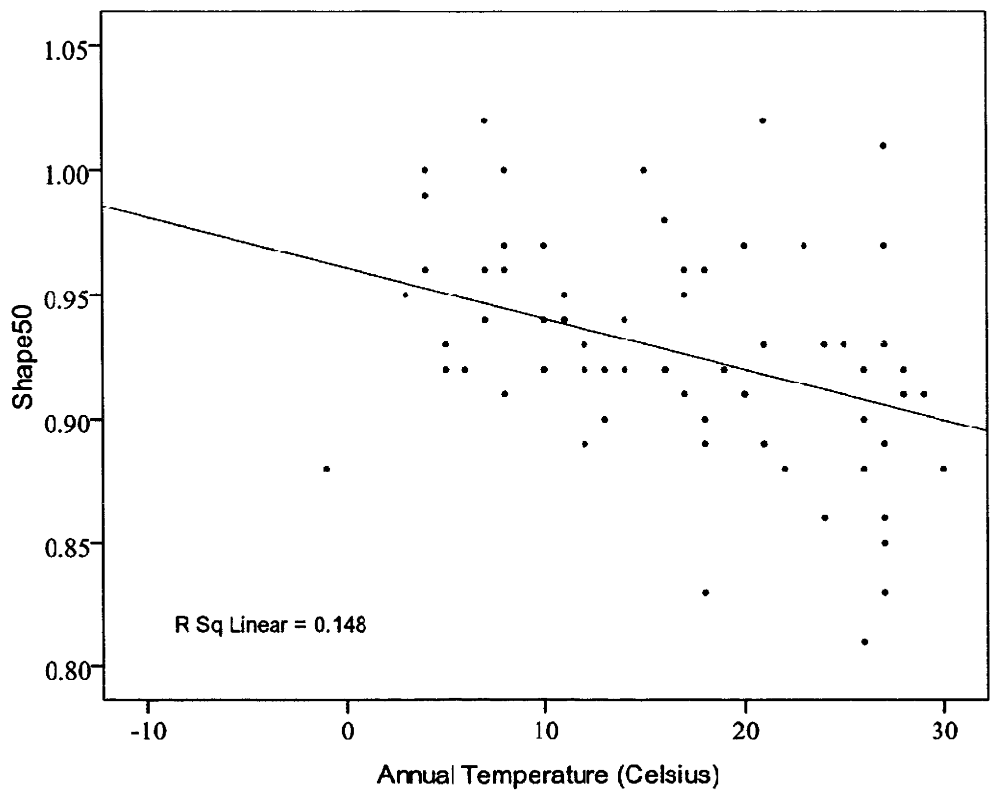
Table 73

Correlations between shaft shape and climate variables, and results of significance tests

Climate variables/ proxies	*n*	*Shape80*		*Shape50*	
		Correlation (r)	*Significance (* $p \leq .006$, 2-tailed)*	*Correlation (r)*	*Significance (* $p \leq .006$, 2-tailed)*
Latitude (°N/S)	71	+.031	.795	+.269	.023
Annual mean temp. (°C)	71	-.151	.208	-.385	.001*
Summer mean temp. (°C)	71	-.399	.001*	-.314	.008
Winter mean temp.(°C)	71	-.005	.967	-.363	.002*

Figure 76

Scatterplot of Shape 50 and mean annual temperature



Shaft Shape and Economy

Descriptive statistics for the two calculated shaft shape variables and economic categories are shown in Table 74, and the distributions plotted in Figures 77 and 78. These show no trend for the proximal femur (consistent with the consensus view that the proximal femur varies more in relation to climate than activity) and a weak trend towards a more antero-posteriorly elongated mid-shaft among forager groups (Figure 78), reflecting greater biomechanical stresses due to higher habitual activity levels among foragers compared to agricultural and urban groups.

Table 74

Descriptive statistics for the shaft shape variables and economic categories

Economic Category		*Shape80*				*Shape50*			
	n	*Min.*	*Max.*	*Mean*	*SD*	*Min.*	*Max.*	*Mean*	*SD*
Forager	24	1.06	1.31	1.21	0.08	0.83	0.97	0.91	0.03
Agricultural	36	1.06	1.34	1.22	0.07	0.81	1.02	0.93	0.05
Urban	11	1.10	1.26	1.19	0.05	0.88	1.00	0.94	0.04

Figure 77

Distributions of Shape80 in the three economic categories

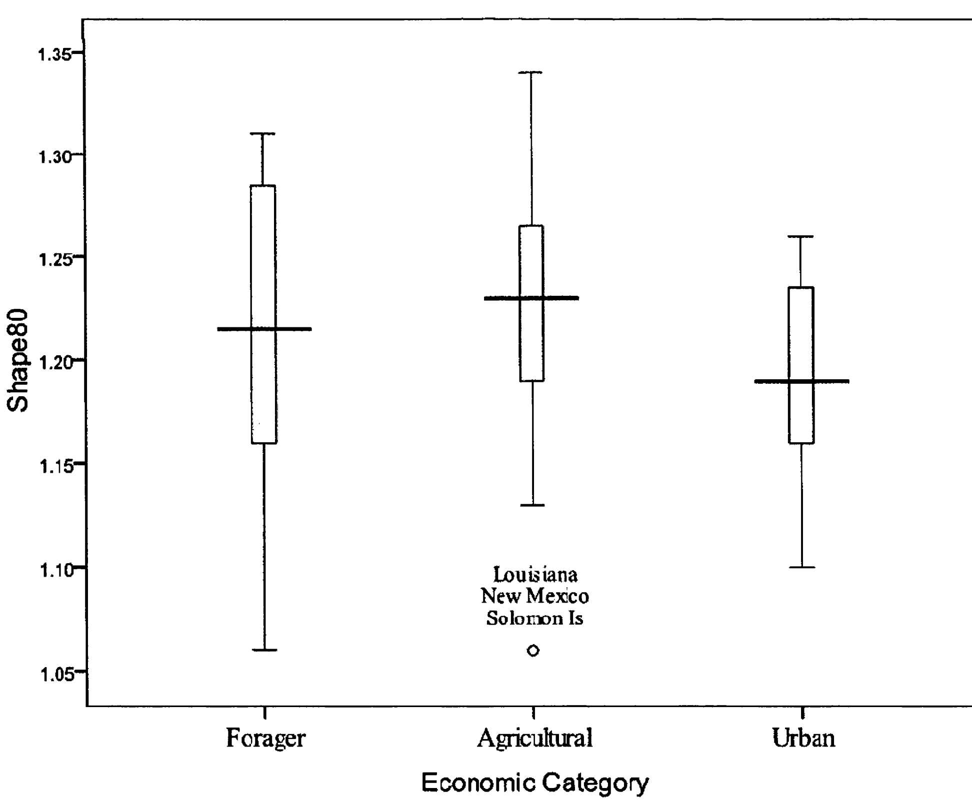
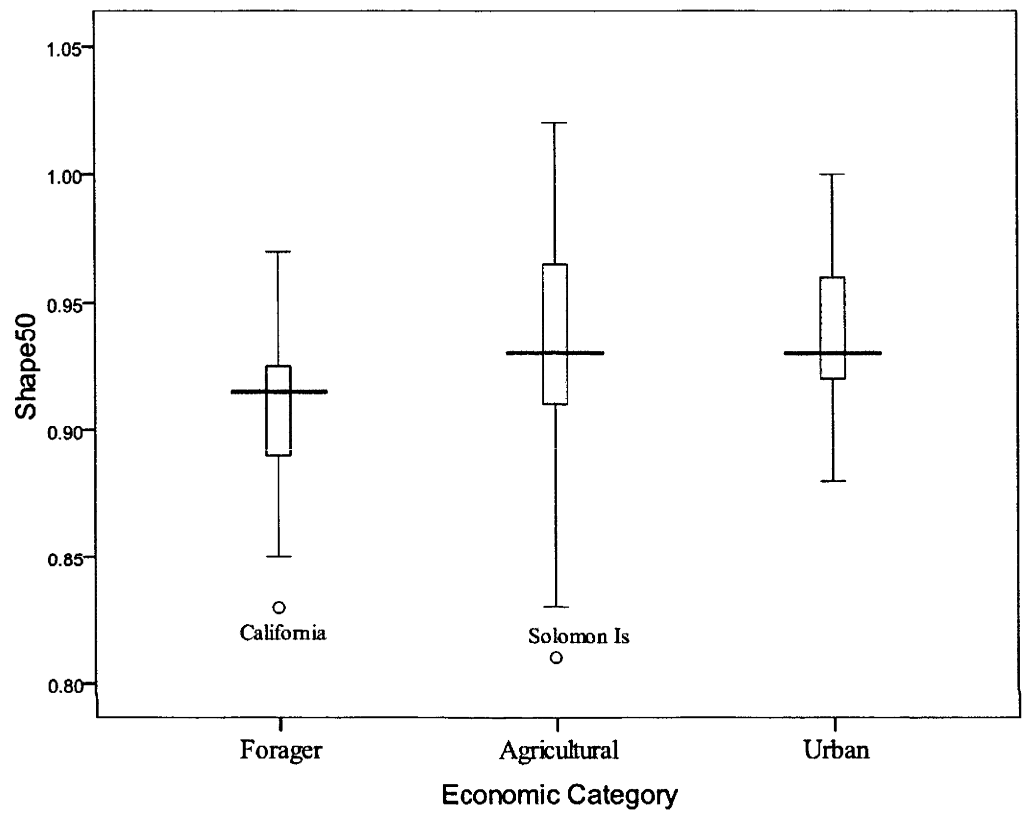


Figure 78

Distributions of Shape50 in the three economic categories



Shaft Shape and Mobility

Descriptive statistics for the shaft shape variables and mobility categories are listed in Table 75. Similar expectations regarding a stronger activity influence at the mid-shaft compared to the proximal femur are seen in the differing distributions for Shape50 (mid-shaft) compared to Shape80 (proximal shaft) in the two mobility categories (Figures 79 and 80).

Table 75

Descriptive statistics for the shaft shape variables and mobility categories

Mobility Category		*Shape80*				*Shape50*			
	n	*Min.*	*Max.*	*Mean*	*SD*	*Min.*	*Max.*	*Mean*	*SD*
Mobile	27	1.06	1.34	1.22	0.07	0.85	0.97	0.92	0.03
Sedentary	44	1.06	1.32	1.21	0.07	0.81	1.02	0.93	0.05

Figure 79

Distributions of Shape80 in the mobility categories

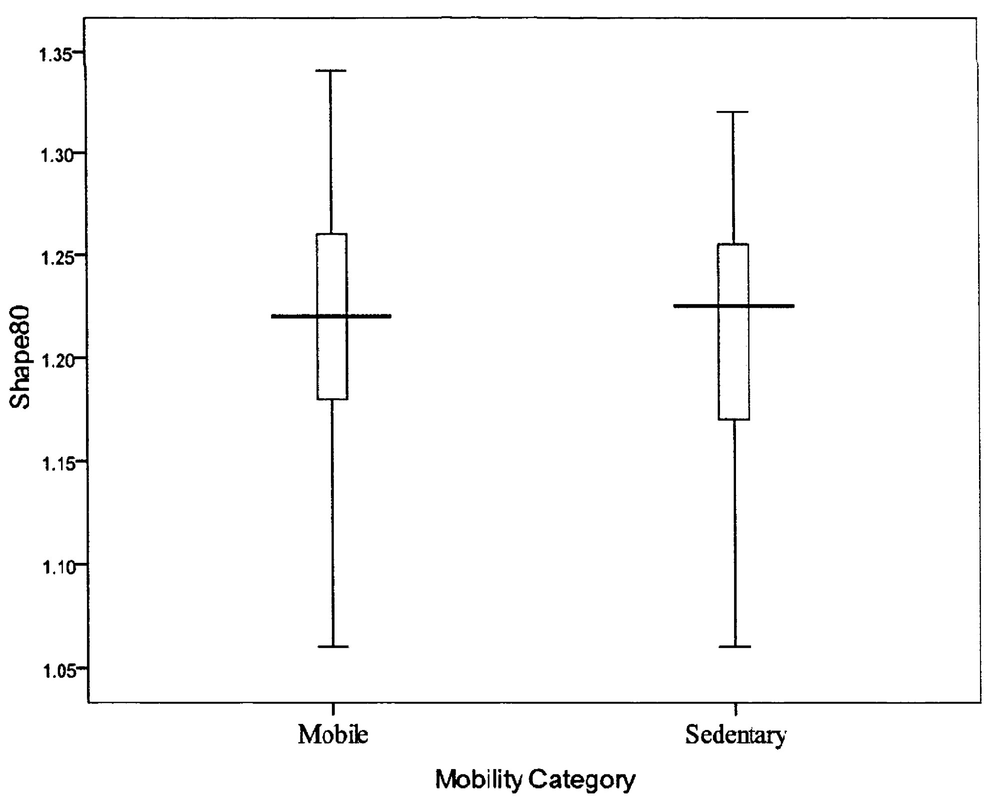
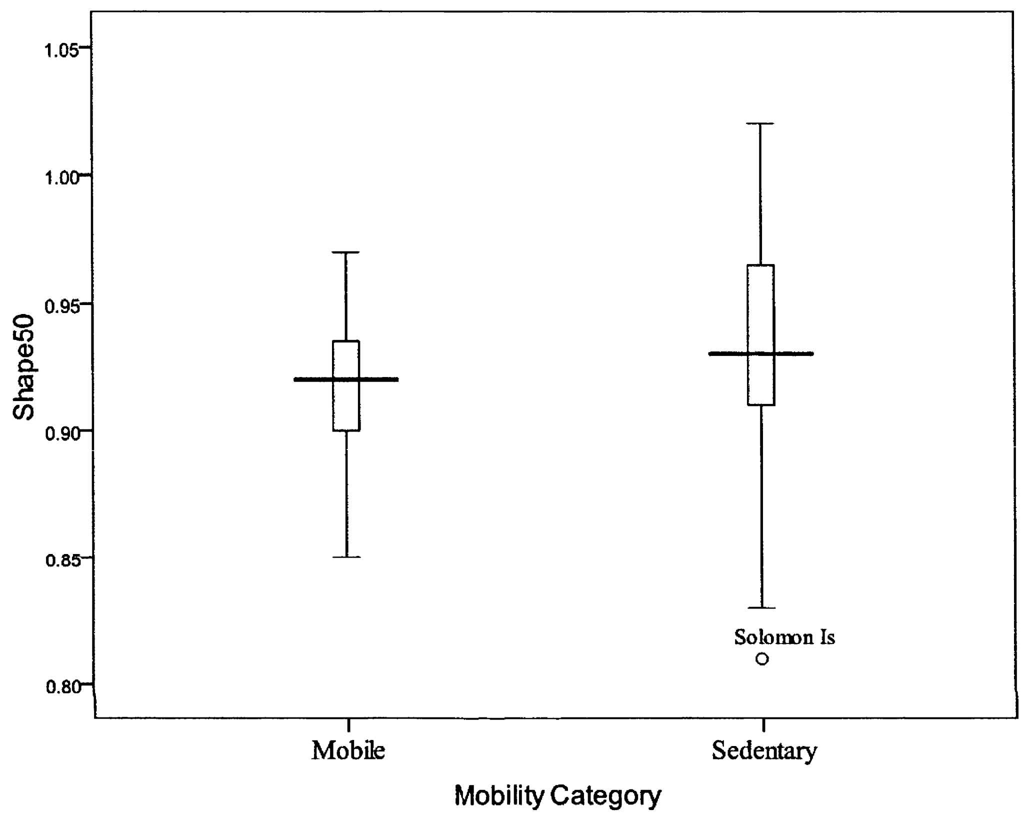


Figure 80

Distributions of Shape50 in the mobility categories



Higher Shape50 scores in the sedentary groups indicate a less antero-posteriorly elongated cross-sectional shape at the mid-shaft level, reflecting less activity-related biomechanical loading in the sedentary compared to mobile groups.

Shaft Shape and Clothing

Descriptive statistics for shaft shape variables and clothing codes are listed in Table 76.

Table 76

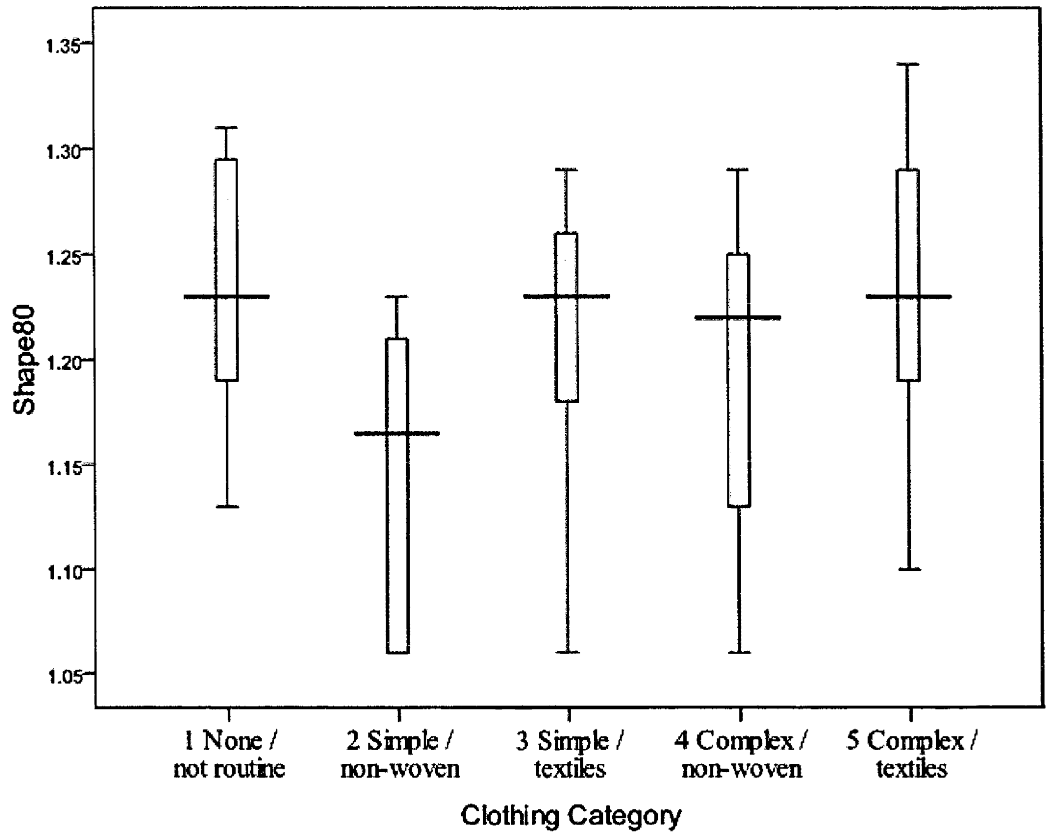
Descriptive statistics for the shaft shape variables and clothing codes

Clothing Category		*n*	*Shape80*				*Shape50*			
			Min.	*Max.*	*Mean*	*SD*	*Min.*	*Max.*	*Mean*	*SD*
1	None / not routine	12	1.13	1.31	1.23	0.06	0.83	0.93	0.90	0.03
2	Simple / non-woven	6	1.06	1.23	1.15	0.07	0.81	0.96	0.89	0.06
3	Simple / textiles	26	1.06	1.29	1.21	0.07	0.86	1.02	0.92	0.04
4	Complex / non-woven	5	1.06	1.29	1.19	0.09	0.88	0.97	0.92	0.04
5	Complex / textiles	22	1.10	1.34	1.23	0.06	0.91	1.02	0.96	0.03

No obvious overall trends between clothing and proximal femoral shaft shape are apparent (Figure 81), which is not unexpected, but a trend towards a less antero-posteriorly elongated mid-shaft with increased levels of clothing is apparent (Figure 82). This latter trend mirrors that seen for the economic categories (Figure 78, page 216), suggesting that the association between the greater use of more-thermally effective clothing among agricultural and urban groups discussed in Chapter 8 (e.g., Figure 47, page 134) might account for this observed relationship between clothing and femoral shaft shape at the mid-shaft (Shape50) level.

Figure 81

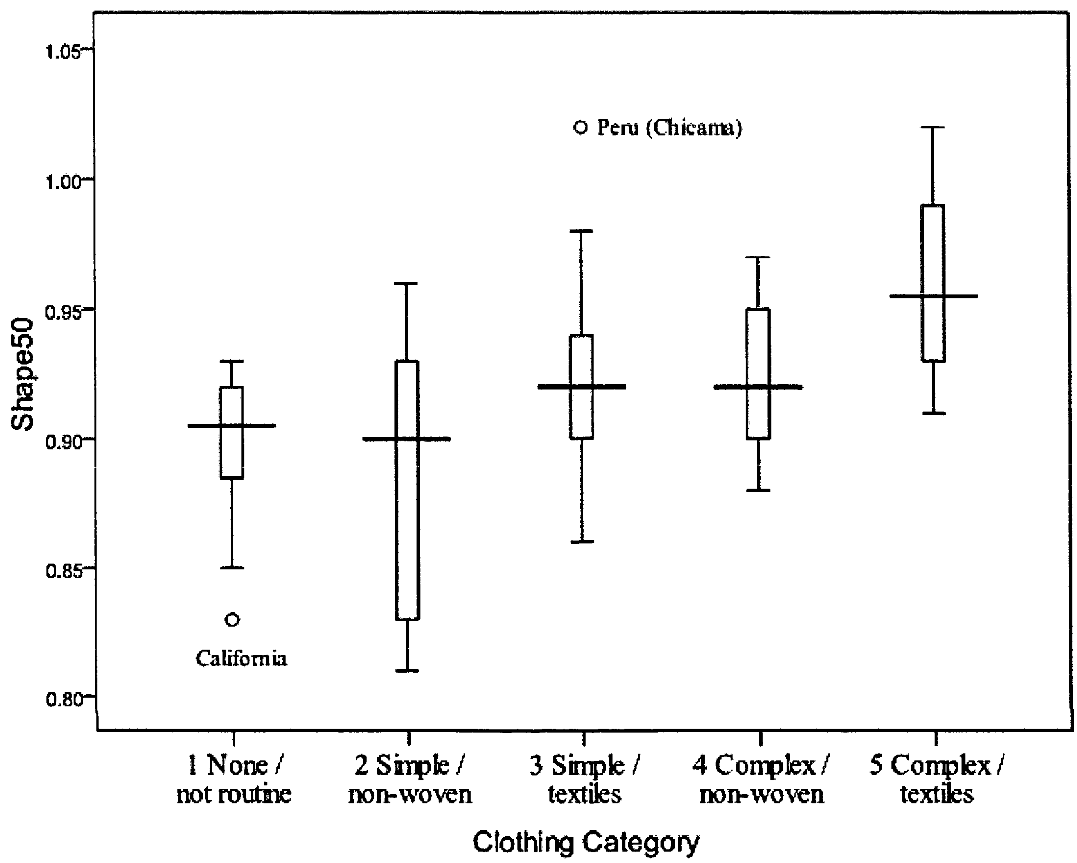
Distributions of clothing codes for the Shape80 variable



In contrast to the marked narrowing of the range of NSA with greater use of more thermally-effective clothing, reflecting the insulating effect of "cultural buffering", it is noteworthy that there are no similar changes in the range of shaft shape variation associated with the different clothing categories. In other words, these results indicate that femoral shaft shape is influenced more by activity levels and associated lifestyle factors than by thermal considerations.

Figure 82

Distributions of clothing codes for the Shape50 variable



Chapter 12: Summary of Femoral Morphology Findings

The femoral morphology study has focused on the NSA as a possible correlate of body build and explored the extent to which its variation at the population level among modern human groups correlates with climatic variation, as should be the case if indeed it relates to global trends in body shape based on thermal considerations. This chapter briefly summarizes the major findings, firstly in terms of the evidence for climatic trends in the NSA, and secondly whether instead its variation corresponds to differing activity levels associated with major lifestyle variables, namely economic and mobility categories. The potential role of clothing as a confounding factor due to a systematic association with the lifestyle variables was explored, with a thermal effect of clothing possibly responsible for the observed lifestyle trends in NSA variation. Anatomical issues concerning the NSA were then examined, relating to questions as to whether the NSA varies with gender, side or advanced age. Finally, results for the other femoral variables measured in the course of the research were presented, with evidence for instance that the cross-sectional shape of the femoral shaft, especially at the mid-shaft level, is affected by habitual activity levels, in contrast to a more dominant climate effect associated with body shape in the proximal femur, consistent with the climatic trends observed in NSA variation.

The initial pilot study in Bangkok resolved practical aspects of measuring the NSA, and the results from this skeletal collection demonstrated a substantial range in NSA within a single population sample (n = 237, mean NSA 126.0°, sample range

22°). Neither a significant gender nor a side difference in NSA was found in the pilot study. A preliminary analysis of the full NSA database (n = 8,271), which comprises 101 samples from around the world, found consistent climatic trends in the NSA. Of the four climatic indices (latitude, and mean annual, summer and winter temperature), the strongest correlations occurred with mean winter temperature, reflecting the role of cold stress in human morphological adaptation to climatic variation. Maximum group variation in NSA was 33° (among the U.S.A. samples), with the largest single sample (the Poundbury sample from England, n = 1,707) having a similar range of 32°. The preliminary analysis revealed generally higher NSA group means in warmer regions, notably in tropical Africa and the Pacific, with groups such as the Andaman Islanders, African Pygmies and Australian Aborigines showing high NSA means (136.1°, 131.6°and 130.2° respectively). Conversely, the lower group means tend to be found in colder regions: examples include the Aleutian Islanders in Alaska (120.6°) and Fuegians (122.4°), with the lowest sample mean deriving from the high-altitude Lake Titicaca area in Bolivia (117.6°).

Climatic trends in NSA are found both between and within the continental regions, with the Pacific region having the highest "continental" mean NSA (129.9°) followed by Africa (128.5°). Climatic trends at the continental level were most marked in Asia but were found on every continent, with the Americas having relatively low NSA group means, a consequence presumably of selection pressure for cold adaptation (and hence a more stocky body shape, and lower NSA) among the likely ancestors of Native Americans in northeastern Eurasia during the late Pleistocene.

In relation to NSA trends associated with differing lifestyle patterns, there is a modest trend towards increasing mean NSA with the transitions from forager to agricultural and urban lifestyles, and, to a lesser extent, from a mobile to a more sedentary existence. The most noticeable trend, however, is for a narrowing in the NSA range associated with these transitions, although climatic trends are nonetheless preserved within each of the economic and mobility categories. The insulatory effects of clothing are implicated in these relationships between lifestyle and NSA variation, however. Greater use of more thermally-effective clothing is associated with the agricultural, urban and sedentary lifestyles, suggesting an underlying thermal rather than an activity effect on the NSA. Multiple regression analysis based on 8,057 femora from 82 groups with adequate sample sizes ($n \geq 10$) highlighted mean winter temperature as the dominant independent variable affecting NSA ($p < .001$), with clothing and lifestyle variables contributing only a marginal improvement in predictive power. Of the latter, only clothing emerged as statistically significant (at the 0.05 level), although interpretation of the regression analysis is hampered by its disappointing overall power (explaining only 5.3% of NSA variation), which may be attributable in part to the massive differences in standard deviations among the dependent and independent variables.

The unprecedented size and geographical coverage of this NSA database allows for resolution of major anatomical questions regarding the NSA. No evidence was found for a gender difference, and any evidence that advanced age (older than 50 years) is associated with a slightly lower NSA is very minor, if present at all. An unexpected anatomical finding is that there exists a small but statistically significant difference between the left and right NSA, with the right femur having a slightly lower NSA (by 1.3°) than the left femur, averaged across the whole database. That this bilateral asymmetry is morphologically as well as statistically significant is suggested by finding a comparable left-right difference (averaging ~2°) among the vast majority (52/62) of groups with adequate sample sizes ($n \geq 5$ for both left and right femora). A sampling of 8 mainland U.S.A. groups shows a similar result: the mean left NSA exceeds the mean right NSA in seven out of the eight groups, with an average bilateral NSA difference of approximately 3°. The most likely reason for this hitherto unreported bilateral asymmetry in the femoral NSA is right leg dominance, resulting in greater biomechanical loading on the right femoral neck during childhood development.

In addition to the NSA, other femoral variables were measured: femoral head diameter (FHD), maximum femoral length (MFL), bicondylar breadth (BCB), and four femoral shaft diameters (creating two cross-sectional shape variables, at the sub-trochanteric and mid-shaft levels). FHD, as expected, shows a large gender difference, and its role as an index of body mass is reflected in significant climatic trends (and, consequently, it correlates with NSA). MFL likewise shows a marked gender difference, reflecting its role as a proxy for stature but, consistent with thermal predictions based on Bergmann's rule, the MFL correlates neither with climate nor with NSA. There is, however, a small but statistically significant side difference with MFL in this large database: the left MFL averages 1.66mm. longer than right MFL, and this unexpected bilateral asymmetry in MFL is consistent with bilateral asymmetry in the NSA. The findings for BCB parallel those for FHD, reflecting its similar role as a proxy for body mass; both the FHD and BCB climatic correlations are stronger for males than females.

In contrast to the weak lifestyle trends for variation in the NSA, variation in femoral shaft shape is attributable more to habitual activity effects related to lifestyle variation than to climatic factors. This is most evident at the mid-shaft level, as anticipated from the literature. Any climatic effects are more pronounced in the proximal femur, where reduced medio-lateral widening is associated with higher summer temperatures, which may reflect a narrowing of the pelvis associated with a more linear body build in hotter climates. At the mid-shaft level, increased relative antero-posterior diameter is found among forager and mobile groups, reflecting a greater habitual activity effect associated with these lifestyle patterns. The only relationship found between the use of clothing and femoral shaft morphology occurs at the mid-shaft level, where a more antero-posteriorly elongated cross-sectional shape occurs with reduced levels of clothing. Rather than being attributable to any thermal effects, this relationship probably reflects an association between reduced use of clothing and the forager and mobile lifestyles, and hence is consistent with the predominant influence of activity patterns on femoral shaft shape.

PART 3: DISCUSSION AND CONCLUSIONS

Chapter 13: Clothing and Hominin Adaptation in the Pleistocene

This thesis highlights two important thermal factors affecting hominin adaptation during the Quaternary: an unusual (by mammalian standards) vulnerability to cold, and the ramifications of that vulnerability in the context of climate change during the late Pleistocene. Among earlier hominins, biological adaptations to heat stress were favoured, including a physiological thermoregulatory system geared to losing body heat, an enhanced capacity for sweating and (coupled with bipedalism) a reduction in body hair cover. Also, Bergmann's Rule resulted in a linear body shape to maximize the ratio of surface area to volume, enhancing the capacity for heat loss. However, these biological adaptations were to present thermal challenges for hominins during the Pleistocene, especially for those who had ventured beyond the tropics. A limited degree of biological cold adaptation was possible among those groups who became established in temperate environments (where exposure to heat stress was reduced), supplemented by behavioural adaptations including the use of fire, shelter and, where necessary, portable protection from cold in the form of clothing.

Hominins in the tropics and subtropics needed to retain biological adaptations to heat stress, and hence any adaptation to cold exposure demanded during the Pleistocene was primarily behavioural. Indeed, retention of biological adaptation to heat stress meant that greater behavioural measures were required as thermal conditions deteriorated, compared to their "cold-adapted" counterparts in temperate zones. This resulted in an earlier development of more sophisticated (i.e., complex) clothing among fully modern humans than among Neanderthals, who could rely mainly on their biological (e.g., morphological) adaptations to cold exposure. Complex clothing was more "expensive" to manufacture in terms of labor and resources but, once the technologies were acquired (along with more efficient methods for their production), such clothing had the distinct advantage of allowing for a rapid development of more thermally-effective protection (e.g., the addition of multiple layers), should cold stresses escalate rapidly. Enhancement of morphological adaptations, in contrast, required much greater time-depth, a luxury that was not available to Neanderthals during the sudden climatic upheavals in late MIS 3.

In other words, there were differing adaptive responses to cold stress between Neanderthals and fully modern humans, with a greater reliance on biological adaptations among Neanderthals. An interaction between biological and behavioural adaptations existed, such that greater development of one was associated with a reduced development of the other. However, these alternative strategies differed in their flexibility and capacity to respond to rapid climate change, and therein lies the reason for the very different fates of these two hominin species in Eurasia during the late Pleistocene.

Clearly, a key issue here is the extent to which morphological variation (specifically, variation in body shape) reflects biological adaptation to climate, since this has significant implications for the development of clothing as a behavioural adaptation to cold. The femoral NSA study undertaken in the course of the present research has focused on this question, examining both for the influence of climate and also for the possible interacting thermal effects of differing forms of clothing.

Implications of the NSA Study

Biological cold adaptations comprise physiological and morphological adjustments, with a key morphological aspect being the relationship between body build and climate. This has been examined here by focusing on one potential osteological marker of body build, the femoral neck-shaft angle (NSA). To the extent that a higher NSA corresponds to a more linear body shape (and vice versa), its variation at the population level may be expected to reflect long-term exposure to ambient thermal conditions. The latter, however, will be affected not only by external climatic variables but also by the buffering or insulatory effectiveness of behavioural adaptations, especially clothing. Given this interaction between morphological and behavioural adaptations, reduction in femoral NSA due to cold exposure should reflect the net cold stress after the thermal protection afforded by clothing is taken into account. At the population level, the routine use of thermally-effective clothing should result in the NSA being less sensitive to climatic variation, whereas a markedly lower mean NSA in cold environments should indicate the presence of less thermally-effective clothing, if any.

Results of a global study of NSA in modern human groups show that the NSA does vary in concert with climate, suggesting that, at the population level, it provides a proxy for body shape variation as a morphological adaptation to the thermal environment. However, the use of more thermally-effective clothing is accompanied by reduced sensitivity of NSA to climatic variation. A similar reduction in climatic sensitivity is seen with agricultural and urban economic groups compared to forager groups, and likewise with sedentary compared to mobile groups, which may reflect the differing levels of clothing associated with these lifestyle categories. Extrapolating these findings to the late Pleistocene, the markedly lower NSA of Neanderthals is consistent with morphological cold adaptation and the use of less thermally-effective (i.e., simple) clothing, whereas the retention of a more linear body shape and tropical proportions among fully modern humans in cold environments suggests attenuated exposure to cold stress, consistent with the use of complex clothing.

Archaeological Evidence for Palaeolithic Clothing

A major component of the present study involves examining the archaeological record of the Pleistocene for evidence of the development of clothing, and exploring the extent to which the proposed differing archaeological signatures of simple and complex clothing are indeed found to occur in patterns consistent with predicted environmental associations. This substantial portion of the thesis is contained in Gilligan (2010), which is presented in Appendix 2 (on CD-ROM). To minimize duplication, only a brief summary (comprising brief excerpts) is reproduced here.

No actual clothing survives from the Pleistocene, yet the archaeological record yields evidence for technological and other correlates of clothing—more evidence than is generally supposed (Table 77). Data from palaeoenvironmental sciences can be utilized in conjunction with findings from human physiology to estimate with some precision the pertinent thermal conditions such as wind chill and hence the human need for clothing.

Table 77

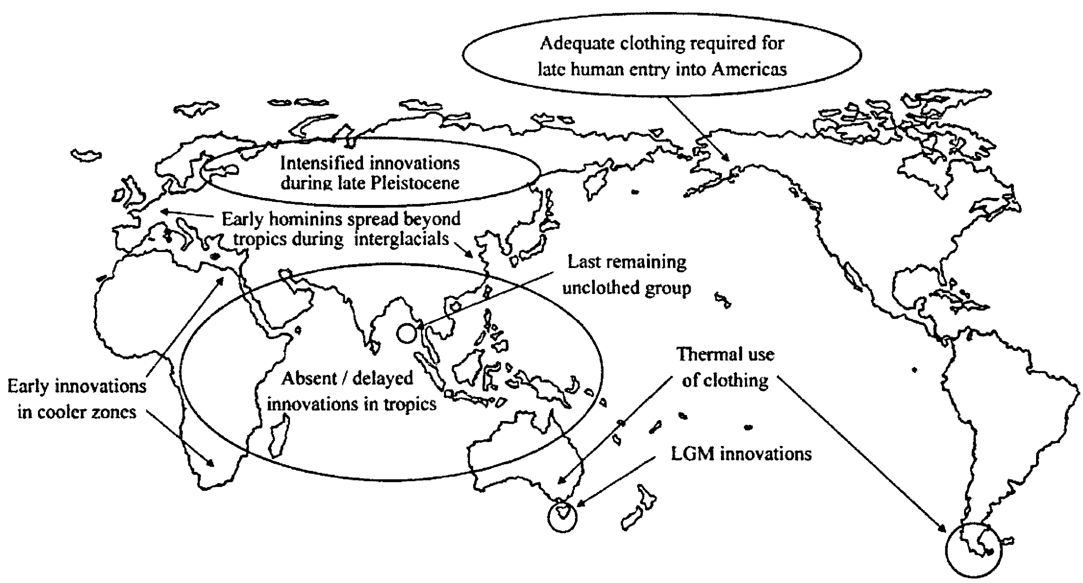
Pleistocene clothing: potential archaeological evidence

Technologies	Scraping, cutting and piercing implements
	(e.g., scrapers, blade-based lithics, awls and needles)
Raw Materials	Faunal / plant exploitation (e.g., faunal targeting)
	Body part distributions (e.g., suggesting skin separation)
Inferred Presence	Known physiological limits to human cold tolerance
	Reconstructed thermal conditions / minimal clothing levels
Anatomical	Morphological cold adaptations, other (e.g., use of shoes)

One theoretical implication is that the acquisition and improvement of clothing assemblages—in concert with environmental contingencies—involved a series of innovations which relate to the large–scale patterning of technological, demographic and behavioural developments documented in the archaeological record of the late Quaternary (Figure 83).

Figure 83

Clothing-related global trends and some of the main archaeological implications of the thermal model

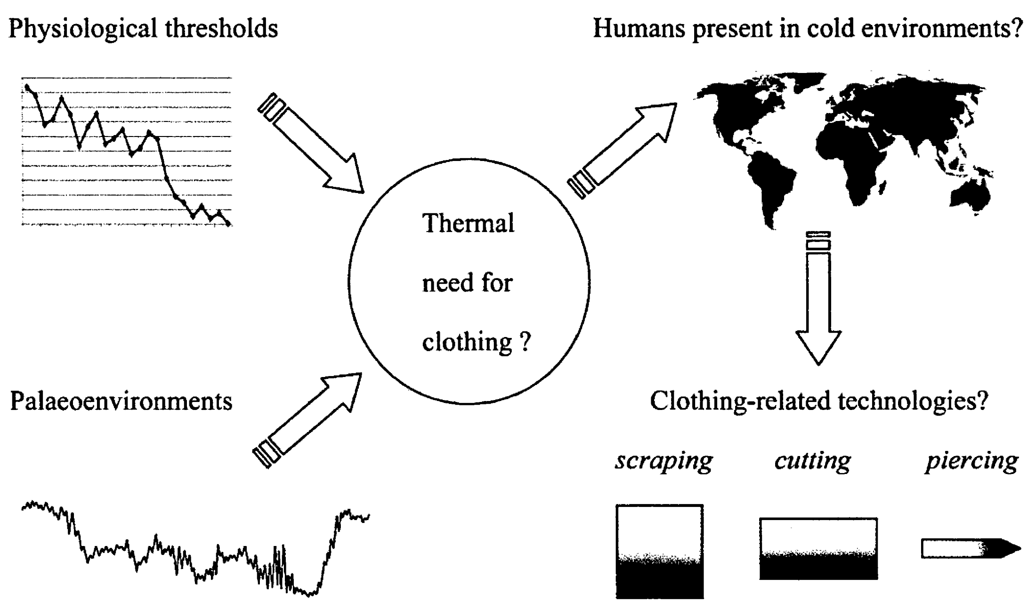


A Thermal Model

The basic principle in this model is that the known physiological thresholds for clothing allow us to predict from palaeoclimatic data those environmental conditions in which clothing (simple or complex) will be required for human survival. In effect, this allows clothing to be rendered archaeologically visible, despite the absence of any actual remains of clothing (Figure 84).

Figure 84

The thermal model, showing how the inferred need for clothing (based on physiological and palaeoenvironmental findings) allows prehistoric clothing to be rendered visible, leading to the prediction of clothing-related technologies in the archaeological record



Regular production of stone flakes for scraping hides should favor the proliferation of recognizable "scraper" tools such as sidescrapers and endscrapers, and an increasing reliance on hides for clothing should result in more efficient production methods—Levallois techniques and (in the case of Neanderthals in western Europe) Mousterian industries, for example. Scraping tools are the main technological correlate of simple clothing, but complex clothing places an additional emphasis on the activities of cutting and piercing hides. These functions will favor a proliferation of more effective cutting and piercing implements, respectively (and also the methods of manufacturing these tools more efficiently). In terms of blade production, methods designed to maximize the amount of useable cutting edge obtained from a core will be favored, with prismatic cores being an example. For the function of piercing, stone points of various descriptions should become more frequent in association with complex clothes, as should longer points made of bone (awls and needles).

The manufacture of simple clothes will highlight the utility of tools for scraping hides, and complex clothes will place an additional premium on the processes of cutting and piercing, and these functions will correspond only loosely to conventional morphological types. Flake tools are generally adequate for these purposes, but the thermal model argues that adaptive pressures (especially where human survival is at stake) will favour production of tools that are more efficient in performing these functions (e.g., Figures 85 and 86). While descriptive categories such as scrapers and blades (based primarily on shape) are not consistently related to function, the functional demands of scraping, cutting and piercing will ultimately favour tools whose shapes are recognized as scrapers, blades and points. Attention is focused on the timing (and environmental contexts) of the early appearance of the tool forms, as well as their proliferation (in terms of quantification and relative proportions in tool assemblages), augmented with findings from use-wear studies.

Figure 85

Sidescraper from Hoxne (top) and endscraper from Timonovka (bottom), with hide-working confirmed by use-wear in both cases (redrawn from Keeley 1980, p. 133, and Semenov 1964, p. 88)

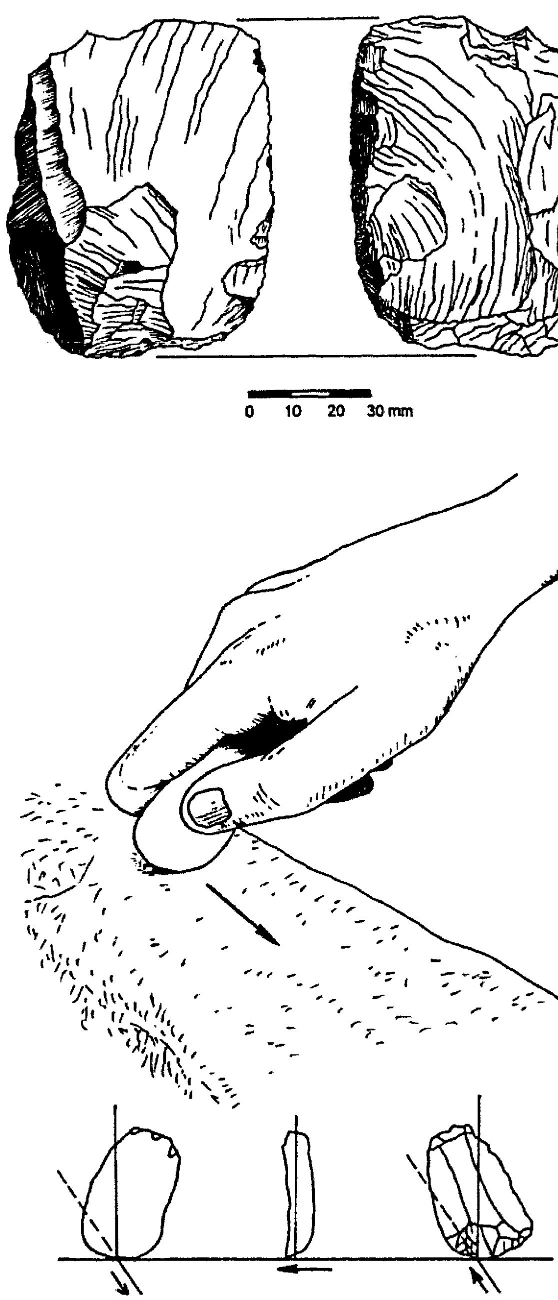
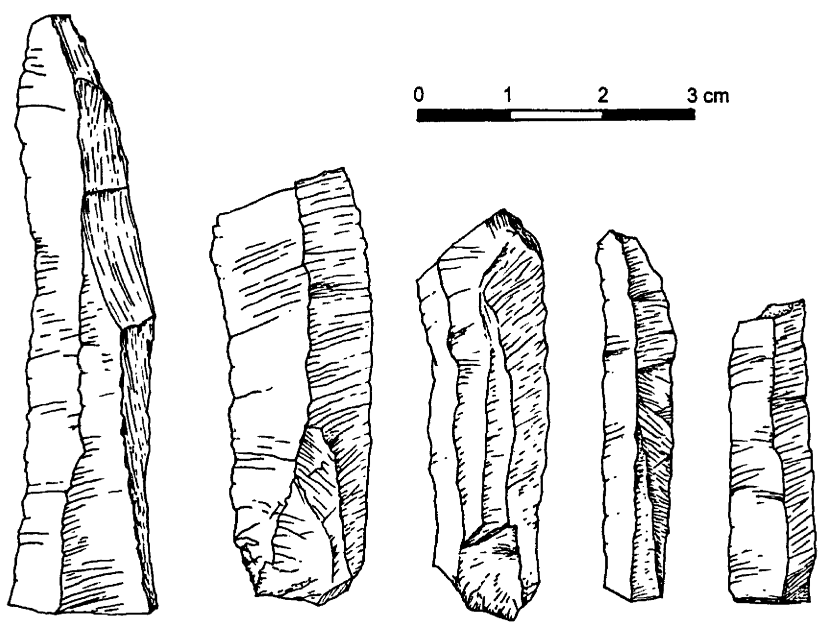


Figure 86

Blade tools dating to MIS 4 from the Howiesons Poort industry at Klasies River Mouth, South Africa (redrawn from Wymer 1982, p. 225)



Middle Palaeolithic

Formal middle palaeolithic assemblages, dominated by various types of scrapers and points, made their appearance in northern and southern Africa and in western Eurasia, to become particularly prevalent in those regions of the inhabited world most affected by climatic changes (Gamble and Soffer 1990, p. 19). In South Africa, some of the earliest Middle Stone Age (MSA) industries begin around 280,000 years ago (during MIS 8) at Florisbad (29° S.), leading to a variant with high levels of retouch dating to 160,000 years ago in MIS 6, the penultimate ice age (Kuman *et al.* 1999). In Europe, the middle palaeolithic dates from around 300,000 years ago with Levallois core-preparation techniques and higher frequencies of retouched flake tools (e.g., Ashton *et al.* 2003), and the increasing dominance of these technologies in assemblages coincides with the colder conditions endured by hominins in these higher latitudes through the last couple of glacial cycles. This is seen for example at the Orgnac 3 site in south-eastern France, where the stratigraphic sequence, which extends from the MIS 9 interglacial around 300,000 years ago into the MIS 8 glacial, documents an increasing dominance of Levallois knapping and the production of formal scraper tools associated with progressively cooler conditions (Moncel *et al.* 2005, pp. 1284-1286).

The extent to which chronological variation within the middle palaeolithic corresponds with environmental variation has been demonstrated in a major study of tool frequencies in western Europe spanning some eight glacial cycles—almost the entire Middle and Upper Pleistocene (Monnier 2006). Results show the association of scrapers with cold periods is highly significant ($p < .001$) (ibid., p. 727). Monnier invokes the scraper reduction model (Dibble 1995) to explain these findings, with access to raw materials being diminished (by snow or ice cover) during glacials. A thermal model, in contrast, highlights the technological implications of clothing requirements, with a gradual increase in scraper frequencies through the whole sequence of glacial cycles reflecting an improved capacity of hominins to adapt behaviourally to cold stress. This shift from a core–shaping focus in the lower palaeolithic (e.g., production of handaxes) to prepared–core technologies aimed at creating more consistent flake tools (often with increased retouch) may be linked not only to greater mobility as humans specialized in the hunting of animals in migrating herds, but equally to a "progressive adaptation of humans to more open and at times cooler conditions" (White and Ashton 2003, p. 606). Within the middle palaeolithic, assemblages such as the "scraper-rich" Quina Mousterian have a "broad association" with colder conditions and the exploitation of hide-bearing species such as reindeer, and this is "highly suggestive" of a relationship to the manufacturing of clothing for thermal protection (M. White 2006, p. 559).

Upper Palaeolithic

The precise cutting of skins required for complex clothes placed a premium on technologies that reliably produced tools with sharp, durable cutting edges. The upper palaeolithic blades of late Pleistocene Europe maximized the usable cutting edge obtainable from flaking stone cores. With their long, sharp cutting edges, these blades were useful in cutting meat, wood and other materials, and were also well-suited for cutting hides into geometric shapes that were joined together to make precisely–fitted garment assemblages, affording multi–layered thermal insulation. Before being cut, hides had to be scraped in order to render them clean and supple (more so than for simple, draped garments), and the importance of end scrapers (often made on blades) for this purpose was stressed by Semenov (1964, pp. 85–93).

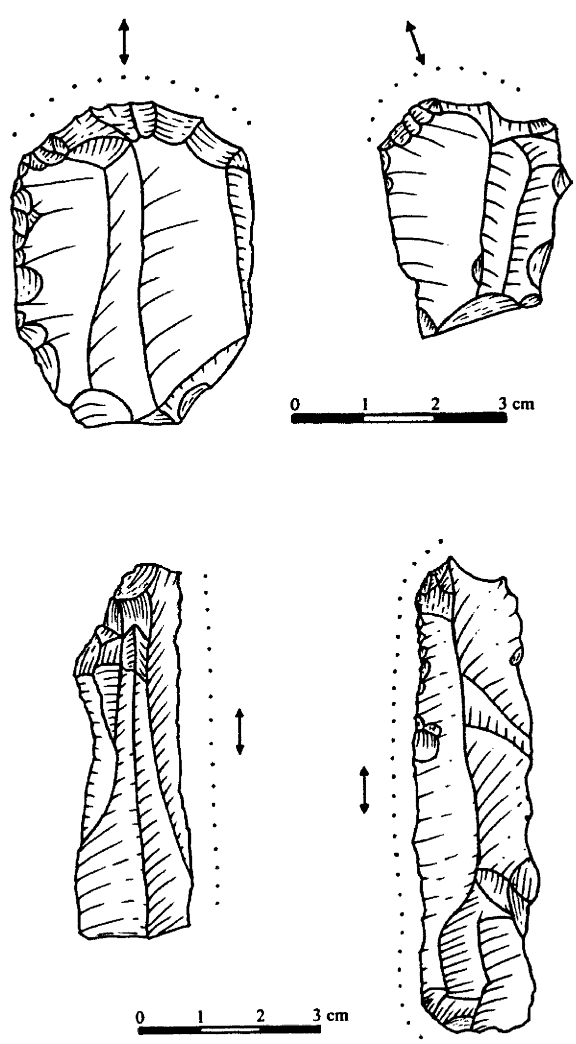
Blade tools had appeared before the late palaeolithic, and evidently in association with cool conditions, although their use in producing complex clothing would be a matter of debate. Blade production waxed and waned in the Near East and in southern and northern Africa (Marks 1990, Bar–Yosef and Kuhn 1999, Gopher *et al.* 2005), beginning towards the end of the very warm MIS 11 interglacial around 400,000 years ago. Early blade tools in Europe occur within middle palaeolithic assemblages at a number of sites in northern France, Belgium and Germany dating from the penultimate glaciation (MIS 6) and also spanning the cold episodes (MIS 5d-b) immediately following the last interglacial (Conard 1990, Delagnes and Meignen 2006, pp. 95-96). In the European upper palaeolithic, industries with blade tools occur during the climatic swings late in MIS 3, by around 40,000 years ago at the Bacho Kiro cave in Bulgaria (Kozlowski 1982), while the middle palaeolithic persists until considerably later (around 34,000 years ago) in the milder region of southern Iberia (Walker *et al.* 2008).

Use-Wear Analyses

Use-wear analyses have identified hide-working as the predominant function of both scrapers and blades at Pavlov I but, consistent with predictions of the thermal model, the inferred working motions for these tool types were quite different: scrapers were used almost exclusively in a transverse (i.e., hide-scraping) direction while blades were used almost exclusively in a longitudinal (i.e., hide-cutting) direction (Šajnerová-Dušková 2007, pp. 26-28). Not only does this use-wear study illustrate the relative importance of hide-working compared to other functions for these tools in the last ice age, the contrasting patterns of hide polish reported for scrapers and blades suggest that the morphological distinction between these basic tool forms corresponds to different hide-working functions. Clearly, in the upper palaeolithic, all the major tool forms such as scrapers, blades and burins performed multiple functions on various materials. Among the commonest of functions was the preparation of animal hides. While this function cut across typological categories, there are indications that scrapers were favoured for the scraping of hides whereas blades were favoured for cutting hides (Figure 87), as predicted by the thermal model.

Figure 87

Use-wear findings from Pavlov I showing different hide-working functions for scrapers and blades: scrapers (top) with a transversal motion indicative of hide-scraping, and blades (bottom) with a longitudinal motion indicative of hide-cutting (redrawn from Šajnerová-Dušková 2007, pp. 35-36)

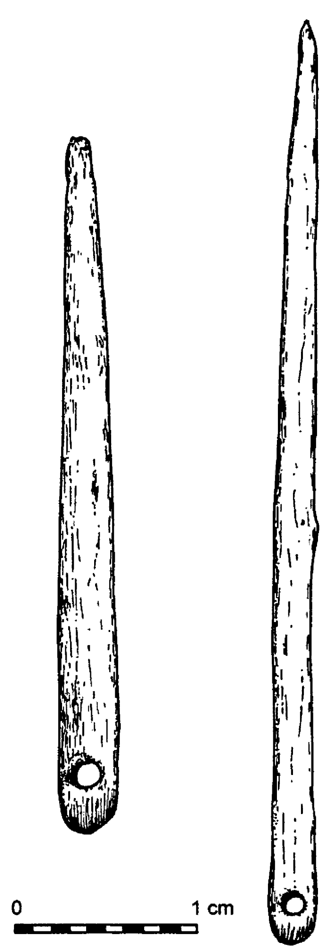


Eyed Needles and Buttons

The late Pleistocene provides compelling evidence for technology associated with complex clothing: the "testimony" of the eyed needle which becomes common in Gravettian and Solutrean industries (Figure 88) during the European upper palaeolithic (de Sonneville-Bordes 1973, p. 54).

Figure 88

Eyed needles from the Solutrean (dating to MIS 2) at Grotte de Jouclas, France (redrawn from White 1986, p. 78)

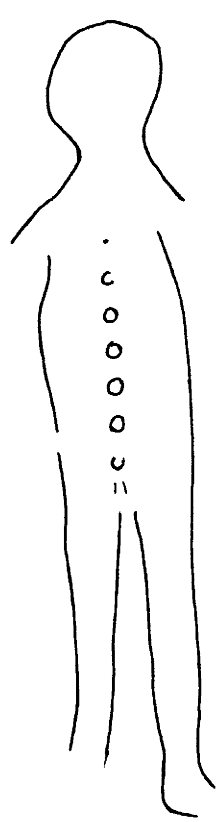


Eyed needles need not be associated exclusively with the manufacture of garments—ethnographic examples illustrate their use for making other items such as bags, tents and fishing nets—but their initial occurrence in the environmental context of the last ice age is strongly suggestive of their primary role in the provision of thermal protection at that time (Semenov 1964, p. 100). Eyed needles in fact appear across the breadth of mid–latitude Eurasia, from western Europe to southern Siberia and northern China, dating from the period of severe cold spikes in late MIS 3 and the LGM. The world's oldest is "probably" from Kostënki 15 in Russia around 35,000 years ago (Hoffecker 2005a, p. 166). Other candidates include those from Denisova Cave in southern Siberia where one date is >37,235 years ago, although stratigraphic uncertainties place the needles more loosely between 43,000 and 28,500 years ago (Kuzmin and Keates 2004, p. 142, Derevianko *et al.* 2005, p. 62, Zilhão 2007, pp. 12–13). There are also needles from the Upper Cave at Zhoukoudian in northeastern China dating to between 33,000 and 27,000 years ago (Chen and Olsen 1990, pp. 282–283). Eyed needles occur at some of the earliest sites in North America, for instance at Broken Mammoth in central Alaska which dates to the Younger Dryas cold event around 13,000 years ago (Hoffecker 2005a, p. 117). Across Eurasia, the geographical distribution suggests that the earliest eyed needles appeared in the colder continental areas during late MIS 3, with later dates (during MIS 2, the LGM) for their first appearance in western Europe.

Perforated discs made of stone and bone (sometimes decorated) that may have served as buttons on garments are documented for the upper palaeolithic (Wymer 1982, p. 249, Ambrose 2001, p. 1752). From the French Magdalenian site of Montastruc there is an engraving of a man with small circles in a vertical line from neck to waist (Figure 89), possibly depicting a front-buttoned cloak, and button-like perforated bone discs occur at several Magdalenian sites (Collins 1986, pp. 251-252). In terms of physiological insulation, the use of buttons allows more flexible responses to thermal stresses, enabling garments to be readily opened (in response, for example, to heat stress generated by high activity levels) or enclosed (in response to colder temperatures and/or wind chill).

Figure 89

Engraving of a human figure with a row of circles, perhaps depicting a garment with buttons, from the Magdalenian at Montastruc, France (redrawn from Wymer 1982, p. 256)

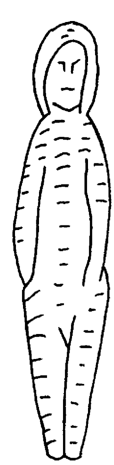


Figurines

In addition to eyed needles and buttons, the upper palaeolithic yields reasonably secure archaeological evidence for complex clothing in the guise of carved figurines and engravings. Besides illustrating the artistic capabilities of modern humans, some of these objects and images indicate the presence of garments that enclose much of the body, with varying degrees of clarity. Among the most convincing are a couple of figurines from the sites of Buret' and Mal'ta, dating to 21,000 and 15,000 years ago (Clark and Piggott 1965, pp. 99-100, McBurney 1976, p. 28, Leroi-Gourhan 1988, p. 166, pp. 656-657). The figurine from Buret' (carved from mammoth tusk) is associated with eyed needles and appears to depict a fitted garment assemblage covering the whole body (Figure 90), including a "parka"-type hood over the head (Collins 1986, p. 251).

Figure 90

Bone statuette of a hooded figure from the LGM at Buret' (Siberia), with markings that may depict a fitted garment assemblage (redrawn from Wymer 1982, p. 248)



Neanderthals and Simple Clothing

This section of the thesis has been published in its entirety (Gilligan 2007a), which is contained in Appendix 1 (on CD-ROM); again, only excerpts are reproduced here.

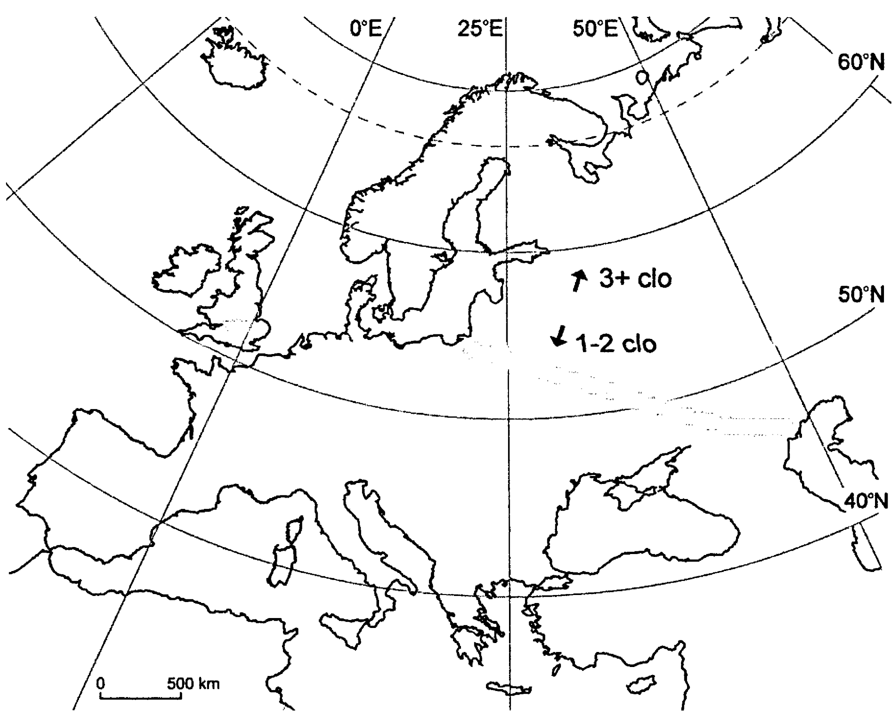
It is now widely acknowledged that the body form of Neanderthals indicates they were biologically cold-adapted (e.g., Trinkaus 1981, Weaver 2003, cf. Condemi 1998), yet this provided them with only limited protection. Whether they had a thicker covering of body hair may never be known, but this would have added at most only another 1 clo or so of insulation. They are also likely to have developed maximal—and possibly, for hominins, unusual—physiological cold defenses (e.g., Steegmann *et al.* 2002), to a greater extent than is found among recent modern human groups adapted to cold climates (e.g., Leonard *et al.* 2002). Given the likely minimum winter temperatures to which Neanderthals were exposed, they would have needed additional portable protection to survive when and where they did (M. White 2006, p. 558). The required level of such protection corresponds broadly to simple clothing, i.e., single-layer, draped garments, and the archaeological evidence is consistent with an absence of complex clothing (e.g., Kuhn and Stiner 2006, p. 958). The work of Trinkaus (2005) suggests a similar situation for footwear, with their pedal morphology indicating that, unlike fully modern humans in late Pleistocene Europe, the use of shoes among Neanderthals was limited. Indeed, their cold-adapted body shape itself suggests the use of only simple clothing, as regular use of complex garments would result in a consistently warmer microenvironment for the body and hence a less cold-adapted physique. The heavier pelts from some animal species would provide more than 1-2 clo protection (M. White 2006, p. 559) even as single-layered, draped garments, since the clo unit is based on lighter modern garments made from woven textiles—although wind penetration would still expose Neanderthals to risk at more extreme wind chill levels. The technological prerequisites for Neanderthal clothing were basic hide-preparation implements, i.e., scrapers and also boring implements to pierce holes in the hides so they could be held in place with strings or cords. Their Mousterian technocomplexes, comprising techniques for reliably generating well-formed scraper tools, were well-suited to the manufacture of simple clothing.

Cool— not Cold—Adapted

One intriguing feature of the archaeological record for Neanderthals is that there was a clear geographical limit to their occupation of ice age Europe (Figure 91), and the most northerly sites date to milder climatic phases (Hublin 1998, p. 305). No confirmed Neanderthal sites are found north of approximately latitude 55°N, and the boundary retreats further south in continental zones where winter minima were lower. Yet as the subsequent expansion of fully modern humans makes clear, colder regions unoccupied by Neanderthals were often rich in resources—and, in terms of extracting food, should have been readily exploitable with Mousterian toolkits. The most plausible explanation is simply that, thermally, the Neanderthals' northern geographical limit marks the limit of their cold adaptations (biological and behavioural).

Figure 91

Map of western Eurasia showing the approximate northern limit to Neanderthal penetration of colder regions requiring 3+ clo of insulation (and hence complex clothing)



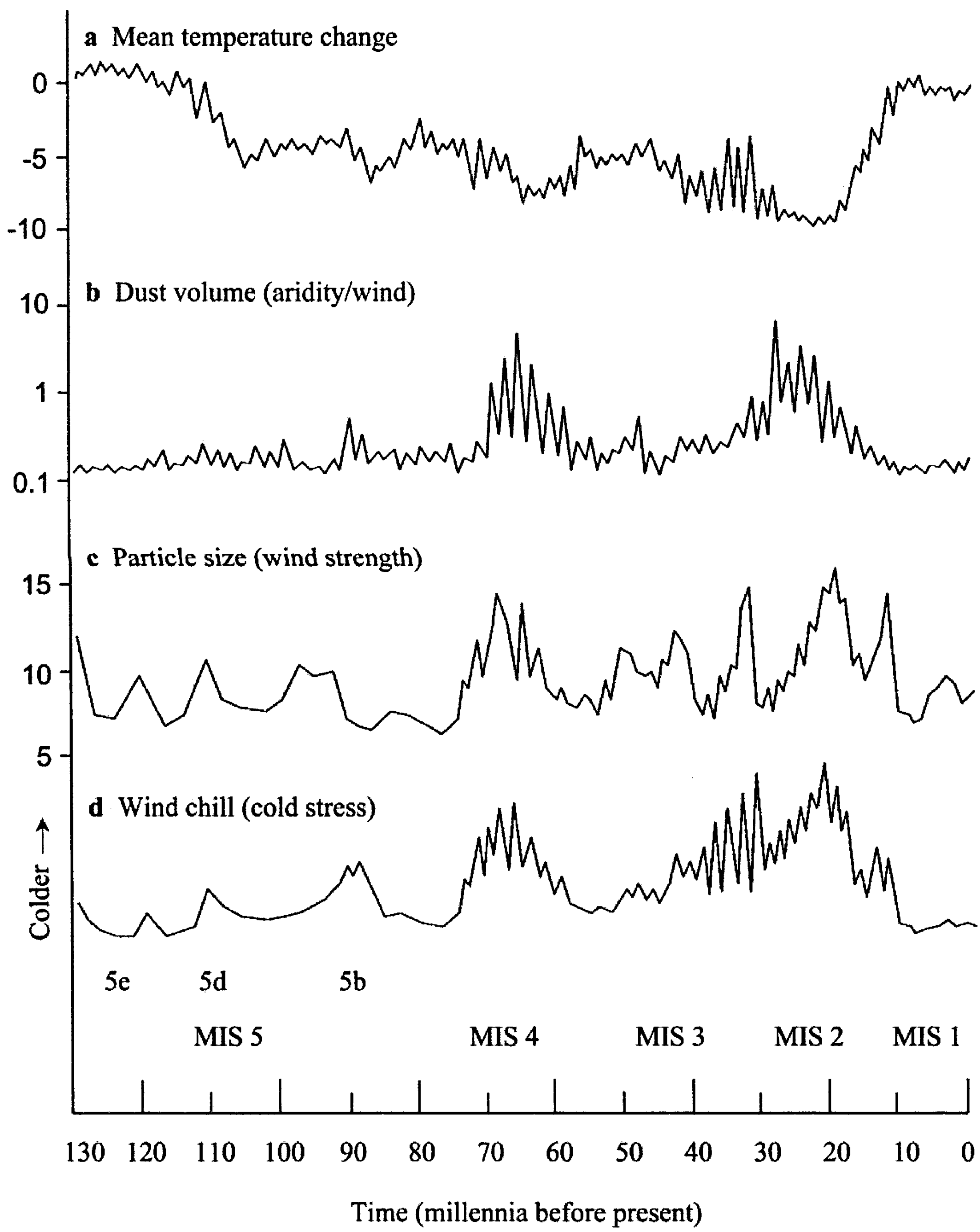
Thermal Conditions in late MIS 3

If the Neanderthals' successful adaptation to moderate cold allowed them and their precursors in the region to survive a number of glacial/interglacial cycles, why might they have struggled (for thermal reasons) late in MIS 3? In terms of mean temperature estimates (Figure 92a), MIS 3 does not appear much different from other stadials and interstadials—milder on average, and at its worst no colder, than MIS 4 (the "mini LGM" *c*. 75,000-70,000 years ago), MIS 6 (the penultimate glaciation), or MIS 2 (the LGM). Yet, on closer scrutiny, there *is* something unusual: a series of "abrupt, whiplash" fluctuations of great magnitude (Macdougall 2006, p. 205). These sudden, severe environmental upheavals would be challenging for many reasons, as the Stage 3 Project emphasized. However, their true significance lies in their special implication for cold stress.

The likely scenario is that these cold spikes corresponded to wind spikes, and the implications for the corresponding wind chill spikes are dramatic (Figure 92d). In terms of wind chill, it is quite possible that thermal conditions in these spikes were at times more dangerous for humans than at any other time in the last ice age, including the LGM. The coldest wind chill conditions in MIS 3 may have been brief but, in terms of the risks to human survival, a period as short as a few weeks or even less would have been catastrophic for populations without sufficient portable protection.

Figure 92

Thermal trends during the last glacial cycle and the Holocene. ***a*** Generalized mid-latitude mean temperature change (°C) from present, based on isotope records from Vostok, Antarctica (Petit *et al.* 1999), GISP2, Greenland (Johnsen *et al.* 2001) and EPICA Dome C, Antarctica (EPICA community members 2004); ***b*** Aeolian dust volume record (mg/m^2/yr) from Dome C (Lambert *et al.* 2008, p. 617); ***c*** Median dust particle size (μm) in the central Chinese Loess Plateau as an average winter wind strength proxy (Xiao *et al.* 1995, p. 26); ***d*** Hypothetical wind chill levels (arbitrary units) based on the temperature and dust records



Hypothermia and Neanderthal Extinction

To what extent is cold stress—hypothermia—implicated as a *direct* cause of Neanderthal extinction? Is there any direct evidence? The short answer is no. Strangely enough, that is what should be expected. Like an ice dagger that soon dissolves, it leaves no trace of a weapon, at least not of the osteological variety. The victim can appear perfectly healthy (aside, that is, from being dead). What about other kinds of cold injury, especially frostbite? This can leave osteological evidence—X-rays of the Tyrolean Iceman, for instance, revealed signs of frostbite in one of his toes (Murphy *et al.* 2003, p. 623)—but resistance to frostbite is a prominent feature of biological cold adaptation. We should not expect to find much evidence for frostbite among Neanderthals—their likely lack of substantial footwear merely underlines the point.

Is there any indirect evidence? The short answer is yes. The whole settlement record for Neanderthals demonstrates their sensitivity to modest levels of cold. The picture for late MIS 3 is most telling in this regard, as the Stage 3 Project made clear:

> If Neanderthals only had a limited cultural capability of insulating themselves, even to the modest level of 1 clo, they would have had difficulty under the increasingly harsh conditions of the latter half of OIS-3.
>
> (Aiello and Wheeler 2003, p. 156)

In effect, if Neanderthals did not have complex clothing, they were finished. Is there archaeological evidence that they had only "a limited cultural capability of insulating themselves" (i.e., only simple clothes)? Yes, there is, and it's called the Mousterian. Without having had prior physiological need to push clothing technologies to the next level, they were insufficiently prepared for the late MIS 3 wind chill spikes. Given the suddenness and severity of the spikes, *pre*-adaptation rather than adaptation was required.

The Chatelperronian: Too Little, Too Late

The obvious question is: why did Neanderthals not begin to develop complex clothing? The short answer is: they did. It is called the Chatelperronian. A longer answer is: they did not need to, at least not until very late—as it happened, too late—in MIS 3.

Looking first at the longer answer, the very biological adaptations that allowed them to manage for so long with simple clothing also meant they did not need to undertake the more labor-intensive manufacture of complex clothes. Up to a point, they would not have felt the cold as acutely as did fully modern humans. Whether any greater body hair cover made more tightly-fitted garments uncomfortable is debatable, although it probably would make multi-layered clothing almost superfluous (again, until it was rather too late). Another aspect is their shortened limbs, the reduced surface area of which reduced the need for the specially-cut sleeves and leg coverings of fitted garments.

The short answer, the Chatelperronian, is the subject of debate in terms of Neanderthal "cultural" capacities and whether the new skills were acquired from fully modern humans or were an independent innovation of Neanderthals (Zilhão *et al.*

2006). The thermal model proposed here need not buy into the debate. It simply points out that there is no reason not to expect that Neanderthals would begin to develop at least some elements of complex clothing (e.g., tailoring, evidenced by bone awls) once their options were narrowed and especially as their situation became desperate. In any case, the Chatelperronian demonstrates that they had a capacity for such behaviour, and the need for complex clothing provides a pragmatic reason as to why such technologies should suddenly become useful (or adaptive) for Neanderthals late in MIS 3.

Modern Humans and Complex Clothing

The cool temperate environments occupied by Neanderthals favoured the development of biological (morphological and, probably, physiological) adaptations to cold, allowing them to tolerate late Pleistocene climatic cooling with limited behavioural cold adaptations. In terms of portable insulatory requirements, adequate protection was provided by simple clothes (draped, single-layer garments), prior to the extreme thermal stresses that accompanied sudden climatic oscillations in late MIS 3. Evidence supporting this thermal scenario derives from multiple sources, including palaeoclimatology (intensified wind chill in late MIS 3), palaeoanthropology (a less linear body build than other hominins, with substantially lowered NSA), and palaeolithic archaeology (the typical Mousterian technocomplex suited to manufacturing simple clothes).

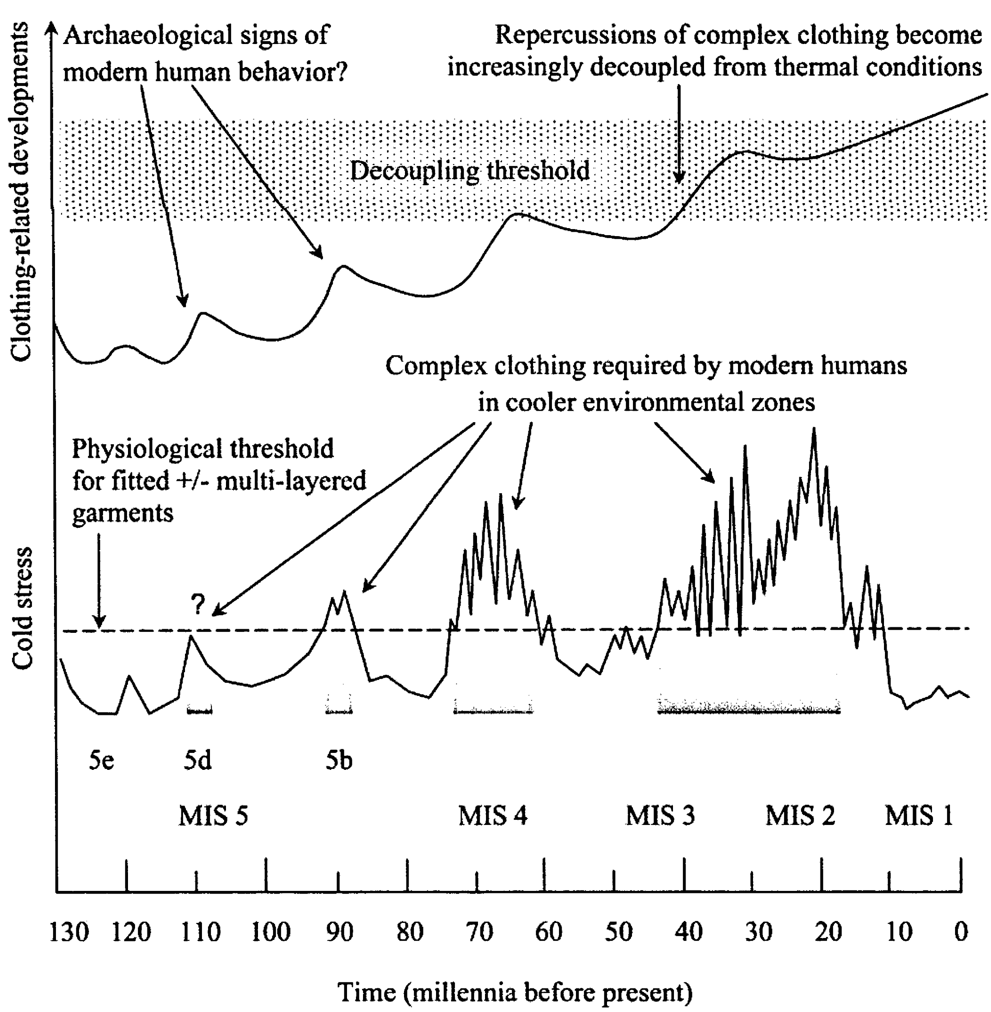
Conversely, the warmer environments occupied by fully modern humans favoured retention of ancestral biological adaptations to heat stress, including a more linear body build (illustrated by a higher average NSA). Exposure to increased winter cold stress in marginal thermal zones (where summers nonetheless demanded heat adaptation) favoured enhanced, flexible behavioural cold adaptations, i.e., complex clothes. This scenario unfolded early in the last glacial cycle (probably, in a few areas, during MIS 5d-5b, and certainly by MIS 4), with the acquisition of complex clothes rendering these groups behaviourally pre-adapted for late MIS 3 (Figure 93).

Biological Vulnerability

Whilst the Neanderthals' biological cold adaptations served as disincentives for developing complex clothing, the reverse was true for fully modern humans. Biological adaptations to heat were crucial to their survival in Africa—summers remained hot even during ice ages, so biological heat adaptations were retained, ruling out opposing cold adaptations. A heightened vulnerability to cold meant that fully modern humans were prompted to begin developing complex clothing before MIS 3. Following the last interglacial—which was warmer than the present one, possibly intensifying selection for biological heat adaptations—the series of cold spells between 118,000 and 70,000 years ago (MIS 5d, MIS 5b and particularly MIS 4) provided the incentive for behavioural cold adaptations. The relatively longer limbs of fully modern humans (suited to maximizing heat loss) would favour an early adoption of fitted garments to provide greater protection of exposed extremities on cold exposure. Technological considerations predict that clothing-related trends (e.g., a proliferation of blade tools, and hide-piercing implements) should become apparent earlier in the more northern and southern parts of Africa, more so during these colder episodes, and this pattern is evident in the archaeological record (Gilligan 2010).

Figure 93

Proposed thermal thresholds for the development of complex clothing in the last glacial cycle (based on wind chill trends), with (upper graph) the recurring but accumulating repercussions which cross a threshold by late in MIS 2, beyond which they become effectively decoupled from thermal contingencies



In other words, the same thermal principles (an interaction between biological and behavioural cold adaptations) that connect Neanderthals with their Mousterian (and Chatelperronian) technologies lead logically to the emergence of additional clothing–related innovations (and, subsequently, LSA/upper palaeolithic techno-complexes) among fully modern humans. As discussed in Gilligan (2010), genetic studies on human body lice dating the "origin of clothing" to early in the last glacial cycle—at least, dating the first regular use of complex clothing among fully modern humans that has continued to the present—are consistent with this scenario.

Beyond the Northern Limit

In late Pleistocene Eurasia, the thermal significance of the upper palaeolithic is that it illustrates how the intensification of trends that had emerged earlier in cooler parts of Africa and the Levant coincides with increased exposure to more intense winter cold stress. In particular, the predominance and elaboration of upper palaeolithic toolkits (comprising, for example, bone awls and techniques for mass-producing blades) corresponds to a greater requirement for (and refinement of) complex clothing. Humans equipped with these technologies were able to exploit wider territorial ranges despite colder conditions and enter northern zones that had been off-limits to those (whether Neanderthals *or* fully modern humans) without such technologies (e.g., Hoffecker and Elias 2003, Pavlov *et al.* 2004).

Complex Clothing and Modern Human Behaviour

A human proclivity for artistic expression and adornment may have little relevance to clothing origins in the thermal model proposed here, but the repercussions of complex clothing for social display have certain archaeological implications—particularly for the emergence of modern human behaviour. The advent of complex clothing can be linked not only to an increasing capacity of fully modern humans to inhabit cooler environments (Hoffecker 2005b), but also to other archaeological signatures of modern human behaviour, including decoration (see McBrearty and Brooks 2000, pp. 491-492 for a list and discussion of the "sig-natures").

Archaeological Signatures

Components of modern human behaviour that can be linked to thermal adaptations include not only technologies (particularly blade-based lithics and bone implements used in the manufacture of complex garment assemblages) but also less tangible aspects. The latter are now viewed as the more archaeologically consistent indicators of behavioural modernity, whereas lithic technologies (and blade-based forms in particular) are considered less reliable (e.g., Hiscock 1996, Bar-Yosef and Kuhn 1999, Bar-Yosef 2002).

Among these other aspects are greater control of fire (e.g., more structured hearths), specialized hunting (for hides and also for meat, to sustain the higher rates of metabolism required in cold environments), sophisticated artificial shelters, greater residential sedentism, increased use of pigment (connected with hide preparation as well as decoration), and various archaeological signs of personal adornment and symbolism (e.g., Van Peer *et al.* 2003, Mellars 2005, Gilligan 2007d). At a more speculative level, some of the further ramifications of the regular covering of the skin surface by complex clothing can include effects on human perceptual capacities and cognitive styles, as well as on interpersonal communications and relationships (with possible implications for the development of social complexity), all of which may, to varying degrees, underlie or accentuate the less tangible features of modern human behaviour. A detailed review of all these aspects falls outside the scope of this thesis, although one example—a proposed link between clothing and archaeological evidence for adornment and artistic expression—can be mentioned here.

Adornment and Art

One pragmatic repercussion of complex clothing is that covering of the skin surface with fitted garments means that decorative and symbolic modification of the human body is displaced elsewhere, onto garments and even into greater symbolic modification of the physical environment. Adornment of the unclad body typically leaves little trace in the archaeological record. Once these decorative and symbolic functions are transferred onto clothing and other media external to the body, they become more visible in the archaeological record.

This same principle applies generally to the evidence for enhanced artistic expression among fully modern humans in the late Pleistocene. An increased frequency of parietal art may similarly reflect a shift from modification and decoration of the exposed skin surface onto alternative surfaces such as cave walls—witnessed briefly in Tasmania (e.g., Cosgrove and Jones 1989). It was further transposed into decorative modification of other external material forms, seen for instance in figurines, a prominent feature of the upper palaeolithic artistic fluorescence in Eurasia during the LGM.

Discoveries in parts of Africa—especially southern Africa, and during MIS 4—are particularly relevant (e.g., Wurz 1999, Henshilwood *et al.* 2001, d'Errico and Henshilwood 2007, Soriano *et al.* 2007). These point to an African origin of developments more traditionally seen as European phenomena including artistic expression, external symbolic representation, and other signs of modern human behaviour. The occurrence of perforated beads in Africa and the Levant dating to around 72,000 years ago (MIS 4) and perhaps from the very beginning of the last ice age (MIS 5d-5b) is pertinent, being cited as key evidence for behavioural modernity (and "symbolic thinking") in the African MSA, prior to the European upper palaeolithic (Henshilwood *et al.* 2004, Jacobs *et al.* 2006, Vanhaeren *et al.* 2006).

Rather than reflecting any heightened mental capacity for such behaviour, an increased frequency of archaeologically-visible art and decorative items (such as beads) reflects a shift from artificial modification of the exposed skin surface onto clothing and alternative surfaces such as cave walls and also into other material forms (such as figurines), once free access to the skin was restricted by its routine and almost complete concealment with multi-layered, complex clothes. This is why, rather than any lack of cognitive, linguistic or other capacities, archaeological signs of such capacities are largely absent among Neanderthals—and why some of the signatures of modern human behaviour (blade tools, bone awls, and decorative beads, for instance) are found with Neanderthals during late MIS 3, when they experienced episodes of greater cold stress.

Nonetheless, adornment of the uncovered body surface may not be completely invisible: one archaeological sign might be the use of colored pigments, which has accompanied hominins since at least Middle Pleistocene times (e.g., Barham 2002). Specific color selection (especially for red ochre) has been advanced as early evidence for behavioural modernity among Near East modern humans who temporarily replaced Neanderthals in the region during a warm spell (MIS 5c) 100-90,000 years ago (Hovers *et al.* 2003). The more common black pigments, however, would be less useful for purposes of body painting among early black–skinned moderns. Moreover, while the alleged colored marker of modernity continues through to the Holocene in Africa, pigment use diminishes among fully modern humans in the Levant during MIS 3 and MIS 2 (when, coincidentally, complex clothing was required), only to resurface during warm oscillations at the end of the last ice age (ibid., p. 510). On the other hand, the higher-latitude homelands of Neanderthals favored not only biological cold adaptation (hence limiting their insulatory requirement to simple clothing, leaving their body surface more available for decoration), it also favored lighter skin color, as these regions lie mainly within ultraviolet Zone 2 (Jablonski and Chaplin 2000, pp. 67-69). Black pigment would be useful for decorating pale skin; indeed, at Peche de-l'Azé, micro-wear abrasions on black (manganese dioxide) colorant blocks are consistent with their decorative use on "matières souples" (supple materials) such as "la peau humaine"—human skin (Soressi and d'Errico 2007, p. 306). Further evidence for the symbolic use of pigments for body decoration by Neanderthals occurs at two sites dating to around 50,000 years ago in southeastern Spain (Zilhão *et al.* 2010).

Archaeological evidence for the emergence of behavioural modernity is evidently connected only loosely—if at all—with anatomical modernity (Zilhão 2007). Instead, its purported biological basis is a nebulous process entailing cognitive reorganization within the human brain that promoted the development of language and other symbolizing abilities—the only evidence for which is the very evidence this invisible revolution seeks to explain (and the underlying cause for which is equally nebulous). An alternative proposal is that behavioural modernity has its roots in "the realm of cultural, demographic, and social processes" (ibid., p. 40)—which, in terms of archaeological visibility and testability, may prove only relatively less nebulous (c.f., Henshilwood and Marean 2003, p. 636) A thermal model, on the other hand, suggests that the advent of modern capacities coincided with the emergence of anatomical modernity (and some of the capacities probably pre-date it). What is visible in the archaeological record is merely greater archaeological visibility of these capacities. This greater visibility, in turn, is largely consequent upon the acquisition of complex clothing and its repercussions—hence an archaeologically testable association with environmental trends and fluctuations.

Rather than attributing the emergence of modern behaviour to purported cognitive changes that are oddly decoupled from the emergence of biological modernity, the regionally variable, often delayed and, in some instances, strangely recurring disappearance and reappearance of its various components are more likely related somehow to the fluctuating environmental contexts within which they occurred (d'Errico 2003, p. 199, Hiscock and O'Connor 2006). A thermal approach suggests a plausible basis for connecting archaeologically detectable expressions of behavioural modernity with environmental change.

The Australian Challenge

That absence of archaeological evidence for modern behavioural capacity cannot be taken as evidence for the absence of such capacity is made clear by the example of Australia (Brumm and Moore 2005, Habgood and Franklin, 2008, cf. Balme *et al.* 2009). Furthermore, there is little that corresponds to the LSA/upper palaeolithic in late Pleistocene Australia and, in comparison to mid-latitude Eurasia, only modest development of MSA/middle palaeolithic technologies. One possible reason is simply that the use of clothing in Aboriginal Australia—even simple clothing—was largely absent from the outset. Humans who moved out of Africa and eventually into Australia by 45,000 BP probably did so without needing to venture far outside of the tropics (Oppenheimer 2004, Bulbeck 2007), and would have had little if any thermal need for clothes.

A thermal view of modern human behaviour nonetheless predicts that some of its archaeological signs should begin to proliferate in Australia if and when wind chill levels approached physiological limits. Indeed, given the general paucity of archaeological markers in the region, Australia offers an excellent test case. The expectation is that any evidence in Australia should be found in the cooler southern regions, especially in Tasmania during the coldest period (the LGM), and that is indeed the case (Gilligan 2007d).

Chapter 14: Conclusions

The primary aim here has been to demonstrate the relevance of human cold vulnerability and climate change during the late Pleistocene to a number of major issues in recent prehistory. Interactions between biological and behavioural cold adaptations are considered to be crucial, both to hominin survival prospects in the face of severe cold stress and the emergence of innovative technological and other behavioural trends that are discernible in the archaeological record.

Thermal considerations can help resolve two of the most challenging problems in later Palaeolithic archaeology—the demise of Neanderthals and the emergence of modern human behaviour. Both can be viewed as reflecting interactions between biological and behavioural cold adaptations, in the context of extreme climatic fluctuations during the Upper Pleistocene. Recent studies draw attention to the special difficulties these conditions posed for humans but few give sufficient regard to the need for adequate pre-adaptations, particularly technologies for manufacturing complex clothing assemblages. It is argued here that pre-existing biological cold adaptations delayed the development of such technological capacities among Neanderthals, resulting ultimately in their extinction. In contrast, the greater biological vulnerability of fully modern humans promoted a precocious appearance of behavioural adaptations among some (though not all) groups, visible in the various archaeological markers of modern human behaviour.

Biological adaptation to thermal environments has been examined here with a study of femoral morphology among modern (Holocene) human groups in relation to climate and the use of clothing—in particular, variation in the femoral NSA at the population level as it may relate to thermally-adaptive variation in body shape. Specifically, a lower NSA may correspond to a more stocky, cold-adapted body build (typified by Neanderthals), whereas a higher NSA may be associated with biological adaptation to warmer environments and a more linear body build (typical of modern humans). Results of the study show that among recent (Holocene) modern humans, the femoral NSA varies in concert with climatic conditions at the global, continental and regional levels. These findings suggest that the NSA may serve as a morphological indicator of biological adaptation to thermal environments at a population level. The results demonstrate also that regular use of thermally-effective clothing is associated with reduced sensitivity of the NSA to climatic variation.

Considered in conjunction with the archaeological evidence for differing technological and other behavioural correlates of manufacturing thermally-effective clothing between Neanderthals and *Homo sapiens* during the late Pleistocene, the lower NSA of Neanderthals is consistent with enhanced biological cold adaptations and hence a reduced need for clothing as thermal protection (compared to modern humans). Conversely, a comparatively higher NSA among modern humans suggests greater biological vulnerability to cold during the late Pleistocene, and hence a physiological impetus to develop improved behavioural adaptations in the form of complex clothing (i.e., fitted garments, with multiple layers when required). Insofar as variation in the NSA offers a proxy measure for morphological adjustment to climate, the retention of a "warm climate" body build among modern humans in late Pleistocene Eurasia provides, in itself, indirect evidence for thermally-adequate cultural buffering from environmental cold stresses.

Various palaeoenvironmental proxies have identified late MIS 3 (approximately 45,000 to 30,000 years ago) as a period of unusually rapid and severe climatic oscillations. With regard to likely wind chill levels, the more extreme conditions that prevailed (however briefly) during these intense cold episodes probably exceeded, at times, the biological capacities of any hominins to survive without effective, flexible behavioural adaptations. In physiological terms, these massive climatic fluctuations demanded the use of complex clothing among hominins in middle latitudes. The archaeological record of the Pleistocene, as reviewed here, yields considerable evidence for an earlier development of technologies and other behavioural correlates associated with the manufacture and use of complex clothing among modern humans, prior to the thermal challenges posed by rapid climate change in late MIS 3. This early acquisition of superior cold protection by modern humans was not based upon superior behavioural capacities. On the contrary, it derived from a biologically inferior capacity to endure cold exposure, compared to Neanderthals. The compensatory behavioural responses to biological cold vulnerability did, however, equip modern humans with technologies that rendered them effectively pre-adapted for the greater thermal stresses of late MIS 3. The archaeological record for Neanderthals, on the other hand, is consistent with their superior biological cold adaptations enabling them to tolerate moderate cold stress with more limited behavioural adaptations—i.e., simple (draped, single-layer) clothing. Among some groups of Neanderthals, the severe thermal stresses that accompanied these climatic oscillations in late MIS 3 prompted a late, sporadic development of technologies and other behavioural correlates associated with manufacturing complex clothing. Nonetheless, given the rapid lethality of hypothermia, the sheer rapidity and severity of these oscillations suggests that, at a population level, the thermal stresses proved ultimately too challenging for those hominins who had not already acquired adequate behavioural pre-adaptations.

An ancillary aim here has been to demonstrate, in principle, how the palaeolithic development of clothing can be rendered more visible archaeologically—and why this matters. It can help to resolve both the paradoxical demise of "cold-adapted" Neanderthals during climatic oscillations preceding the LGM, along with the otherwise problematical delays in the early appearance (and the uneven presence) of certain technological innovations and markers of behavioural modernity among modern humans. Unlike existing approaches, clothing-related issues (both physiological and technological) directly address fundamental aspects of hominin adaptation in the late Pleistocene and make no unfounded assumptions about nebulous cognitive, linguistic or other capacities, the evidence for (and relevance of) which is hardly more substantive than are physical remains of Pleistocene clothing. Likewise, it negates any need to attribute the enigmatic Chatelperronian to contact between Neanderthals and modern humans, and similarly any need to invoke competition between these two human groups. It does, however, uncover pragmatic, adaptive reasons for the emergence of certain markers of behavioural modernity and equally pragmatic reasons why these conferred advantages upon many (though not all) groups of fully modern humans in the context of late Pleistocene climatic changes. Moreover, both the early African developments and the later Eurasian intensification of the trends during the LGM are accommodated, as are the generally weaker archaeological signatures of behavioural modernity in warmer parts of the Pleistocene world, notably in the southern Asian and especially the Australian regions.

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APPENDICES

Appendix A4

Complete list of NSA means for the 101 samples, showing sample size (*n*) and the mean, minimum, maximum and standard deviation (SD) values.

Samples	*n*	*Minimum*	*Maximum*	*Mean*	*SD*
AFRICA					
Algeria	53	115	131	123.4	4.1
Angola	11	122	133	128.7	3.2
Benin	10	122	138	130.1	4.6
Canary Islands	223	110	140	125.7	5.7
Central African Rep.	5	122	135	128.2	5.3
Chad	10	124	138	132.3	4.2
Congo	6	113	138	123.7	10.4
Cote d'Ivoire	1	128	128	128.0	0.0
Egypt	136	112	140	127.0	5.0
Equatorial Guinea	2	123	131	127.0	5.7
Ethiopia	5	124	136	132.2	4.8
Gabon	25	119	138	130.0	5.1
Gambia	2	143	145	144.0	1.4
Ghana	2	125	126	125.5	0.7
Guinea	2	132	135	133.5	2.1
Madagascar	62	114	136	126.1	4.9
Mali	53	122	142	130.8	5.1

Morocco	59	114	130	120.0	3.4
Mozambique	10	112	126	120.8	3.7
Niger	43	117	140	129.0	5.1
Nigeria	2	129	130	129.5	0.7
Senegal	8	127	143	132.5	5.2
Somalia	47	117	139	125.5	4.7
South Africa	34	114	142	129.7	7.5
Sudan	130	118	143	130.5	4.4
Tanzania	161	117	142	127.8	5.0
Tunisia	2	125	126	125.5	0.7
ASIA					
Bangladesh	2	126	126	126.0	0.0
China	115	113	139	127.2	5.0
India	47	115	140	129.9	5.0
Indonesia	11	125	136	131.6	3.2
Iran	6	114	131	125.2	6.2
Japan	251	113	140	127.2	4.6
Kampuchea	2	126	129	127.5	2.1
Laos	2	128	130	129.0	1.4
Malaysia	5	127	139	132.8	5.0
Nepal	2	126	130	128.0	2.8
Nicobar Islands	12	122	142	131.6	5.5
Pakistan	4	122	129	126.3	3.1
Philippines	92	113	141	128.6	4.5

Siberia	18	120	136	130.0	4.1
Sri Lanka	16	127	136	129.7	2.7
Syria	15	115	134	125.3	6.2
Thailand	457	114	141	127.5	4.8
Turkestan	4	119	124	121.5	2.1
Vietnam	16	116	141	126.3	7.8
AUSTRALIA					
(South) Australia	47	119	139	130.2	4.8
EUROPE					
Armenia	2	128	129	128.5	0.7
Belgium	6	117	132	125.3	6.6
Cyprus	2	116	121	118.5	3.5
Czech Republic	56	116	139	126.8	5.0
England	1271	108	142	125.5	5.5
Estonia	4	123	130	126.0	3.3
Finland	2	121	122	121.5	0.7
France	768	112	142	127.0	5.3
Iceland	146	114	138	126.6	4.2
Italy	10	119	134	127.7	4.3
Norway	4	122	132	126.0	4.2
Poland	8	116	131	125.3	5.6
Russia	46	111	135	126.0	5.4
Scotland	434	116	142	127.7	4.9

Spain	14	112	131	124.2	5.0
Sweden	2	121	123	122.0	1.4
Ukraine	10	117	132	124.8	4.9
Wales	2	125	126	125.5	0.7
NORTH AMERICA					
Canada	272	113	135	124.2	4.3
Dominican Republic	24	118	136	124.3	4.0
Greenland	90	118	141	129.3	4.2
Guadeloupe	4	115	123	120.8	3.9
Mexico	65	112	138	126.5	5.2
U.S.A.	987	109	142	125.6	5.3
PACIFIC					
Easter Island	94	117	135	126.7	3.9
Fiji	3	130	136	133.3	3.1
Guam	2	126	131	128.5	3.5
Hawaii	12	126	142	132.9	4.5
Kiribati	4	125	132	128.3	3.3
Marquesas	2	125	127	126.0	1.4
New Zealand	20	116	131	124.3	4.9
Papua New Guinea	59	121	142	132.0	4.4
Solomon Islands	20	124	136	132.4	2.9
Tahiti	11	125	140	132.5	4.6
Tonga	4	115	143	129.5	14.5

Vanuatu	76	123	141	130.9	3.8
SOUTH AMERICA					
Argentina	108	114	143	128.9	4.8
Bolivia	33	105	126	117.6	4.3
Brazil	9	126	130	128.1	1.4
Chile	49	105	136	124.5	5.6
Ecuador	193	112	144	125.9	4.9
Peru	211	109	136	122.2	5.4
Surinam	4	122	131	127.3	3.9
Venezuela	68	115	141	127.0	6.0
OTHER GROUPS					
Ainu	233	112	136	125.3	3.9
Andaman Islands	81	125	148	136.1	4.4
Bushmen	35	120	131	126.7	2.7
Fuegian	34	112	128	122.4	3.8
Inuit	324	109	131	120.2	4.1
Moriori	25	120	141	130.9	4.7
Negrito	37	125	137	130.9	3.6
Okhotsk	19	118	132	124.8	4.0
Pygmy	16	125	139	131.6	3.9
Sami	12	121	128	125.3	2.2
Veddah	16	126	139	132.3	3.7

Appendix A5

Institution Visits

Dates and durations (approximate, in 5-day weeks, including travel) of visits, and number of femora measured (*n*) at each institution.

Location / Institution	*n*	Dates visited	Weeks
Bangkok (CAM)	243	28 March - 15 April, 2007	3
Chiang Mai (CMU)	214	6 August - 10 August, 2007	1
Tokyo (NMNS)	331	12 August - 19 August, 2007	1
Sapporo (SMU)	172	20 August - 24 August, 2007	1
Washington (Smithsonian)	1338	17 September - 2 October, 2007	2
Harvard (Peabody Museum)	281	2 October - 16 October, 2007	2
New York (AMNH)	436	16 October - 27 October, 2007	2
Florida (FLMNH)	306	27 October - 3 November, 2007	1
London (NHM)	1991	21 September - 15 October, 2008 +	
		18 November - 5 December, 2008	4
Cambridge (LCHES)	350	6 October - 13 October, 2008	1
Paris (Mdl'H)	2307	13 October - 12 November, 2008	4.5
Paris (IdPH)	255	13 November - 17 November, 2008	1
Adelaide (SAM)	47	9 December - 11 December, 2008	0.5
Totals	8271		24